APTD-0754

PB 203 502

ADMINISTRATIVE AND TECHNICAL ASPECTS OF SOURCE SAMPLING FOR PARTICULATES

PREPARED BY

PEDCo-ENVIRONMENTAL SPECIALISTS, INC.
SUITE 8, ATKINSON SQUARE
CINCINNATI, OHIO 45246

CONTRACT NO. CPA 70-124

ENVIRONMENTAL PROTECTION AGENCY
TECHNICAL CENTER
RESEARCH TRIANGLE PARK, NORTH CAROLINA

MAY 1971

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

A

135

BIBLIOGRAPHIC DATA SHEET

1. Report No. APTD-0754

2.

3. Recipient's Accession No.

4. Title and Subtitle
Administrative and Technical Aspects of Source Sampling for Particulates

5. Report Date June 7, 1971

6.

7. Author(s) R. W. Gerstle, D. J. Henz

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
PEDCo-Environmental Specialists, Inc.
Suite 8, Atkinson Square
Cincinnati, Ohio

10. Project/Task/Work Unit No.

11. Contract/Grant No. CPA-70-124

12. Sponsoring Organization Name and Address
Environmental Protection Agency
Division of Applied Technology
1033 Wade Avenue, Raleigh, N. C. 27605

13. Type of Report & Period Covered Final Report

14.

15. Supplementary Notes

16. Abstracts

The technical and administrative aspects of establishing and conducting a source sampling program within an air pollution control agency are presented. Administrative aspects include legal aspects, organization, personnel and equipment needs, and costs. Technical aspects and a detailed explanation of conducting a source sampling test for particulate matter are described. Sources of error and the magnitude of errors are included.

17. Key Words and Document Analysis. 17a. Descriptors

Air Pollution
Source Sampling
Particles
Management
Regulations
Staff (personnel)
Equipment

17b. Identifiers/Open-Ended Terms

Source sampling
Particulates

17c. COSATI Field/Group 13B

18. Availability Statement Unlimited

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) S UNCLASSIFIED

21. No. of Pages 135

22. Price

USCOMM-DC

FORM NTIS-35 (10-70)

ADMINISTRATIVE AND TECHNICAL ASPECTS OF SOURCE SAMPLING FOR PARTICULATES

Prepared by
PEDCo-Environmental Specialists, Inc.
Suite 8, Atkinson Square
Cincinnati, Ohio 45246

Contract No. CPA 70-124

ENVIRONMENTAL PROTECTION AGENCY
Technical Center
Research Triangle Park, North Carolina

May 1971

This report was furnished to the Environmental Protection Agency by PEDCo-Environmental Specialists, Inc. in fulfillment of contract number CPA 70-124. The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions are those of the authors and not necessarily those of the Environmental Protection Agency. Mention of company or product names does not constitute endorsement by the Environmental Protection Agency.

Acknowledgments

The principal authors of this report were Messrs Richard W. Gerstle and Donald J. Henz of PEDCo-Environmental Specialists, Inc.

Mr. Gene W. Smith of the Office of Air Programs, Environmental Protection Agency was the project officer.

TABLE OF CONTENTS

Section	Page
List of Figures	vii
List of Tables	ix
INTRODUCTION	1
1.0 SOURCE SAMPLING PROGRAM	2
2.0 FUNCTIONS OF THE SOURCE SAMPLING UNIT	3
2.1 Specific Duties Assigned to the Source Sampling Unit	4
3.0 REGULATIONS REQUIRED TO CONDUCT SOURCE SAMPLING	6
3.1 Statutory Authorization to Establish Program	6
3.1.1 State Programs	6
3.1.2 Local Programs	7
3.1.3 Litigation of Source Sampling Regulations	8
3.2 Regulations Requiring Source Sampling and Monitoring	8
3.2.1 Tests by the Agency	8
3.2.2 Tests by the Owner-Operator	10
3.3 Search Warrants	10
3.4 Typical Statute Codes and Regulations	11
3.4.1 State Statutes	11
3.4.2 Regulations of State and Local Agencies	13
4.0 LEGAL USE OF SOURCE SAMPLING INFORMATION	18
4.1 Taking the Sample	18
4.1.1 Test Equipment	19
4.1.2 Test Personnel	21
4.2 Transportation of the Sample	22
4.3 Identification of the Sample	23
4.3.1 Identification of Filters and Containers	23

TABLE OF CONTENTS

Section Page

4.4 Handling and Chain of Custody 23

4.5 Laboratory Analysis and Calculations 24

4.6 Custody of Final Report and Data 25

5.0 ORGANIZATION AND ADMINISTRATION OF A SOURCE SAMPLING UNIT 27

5.1 Organizational Plans 27

5.2 Personnel Requirements 34

5.2.1 Manpower Needs 34

5.2.2 Test Team Personnel 36

5.2.3 Personnel Costs 37

5.3 Equipment and Space Requirements, and Associated Costs 38

5.3.1 Equipment and Costs 38

5.3.2 Space Requirements and Costs 39

5.4 Administrative Procedures 39

5.4.1 Request for Source Test 39

6.0 PRELIMINARY PROCEDURES REQUIRED IN CONDUCTING A STACK TEST 44

6.1 Pre-Survey Process Information 44

6.2 Selection of Test Site 51

6.3 Preliminary Determination of Test Parameters 51

7.0 PARTICULATE SAMPLING PROCEDURES 53

7.1 Measurement of Stack Gas Velocity and Related Parameters 53

7.1.1 Location of Traverse Points 53

7.1.2 Velocity Head Measurements 58

7.1.3 Temperature and Static Pressure Measurements 61

7.1.4 Gas Density and Moisture Determination 64

TABLE OF CONTENTS

Section Page

7.1.5 Calculation of Velocity and Total Gas Flow 66
7.2 Determination of Isokinetic Sampling Rates 67
7.2.1 Calculation Aides 69
7.3 Non-Ideal Sampling Conditions 73
7.3.1 Poor Flow Distribution 74
7.3.2 Non-Isokinetic Sampling Conditions 74
7.3.3 Cyclic Flow Conditions 75
7.4 Particulate Sampling Equipment 76
7.4.1 Description of Sampling Train 76
7.4.2 Assembling and Testing the Train 80
7.5 Sampling Procedure 84
7.5.1 Location of Sampling Points 84
7.5.2 Length of Sampling Period 84
7.5.3 Operation of Sampling Train 84
7.5.4 Recording Data During Test Period 85
7.5.5 Sampling Problems 92
7.6 Disassembly and Particulate Clean-out Procedure 92
7.7 Particulate Analysis 94
7.8 The Test Report 97
7.8.1 Format of the Test Report 97
7.8.2 Presenting the Results 98
7.8.3 Example Calculations 99
8.0 SIGNIFICANCE OF ERRORS IN SOURCE SAMPLING 107
APPENDIX A - Nomographs for Sampling 115
APPENDIX B - Cleaning of Sampling Train Components 118
APPENDIX C - Orifice Calibration 120
LIST OF SYMBOLS 123
REFERENCES 124

LIST OF FIGURES

Figure		Page
5.1	Organization Chart - State of New Jersey Bureau of Air Pollution Control	28
5.2	Current Organization Chart - State of New Jersey Air Pollution Control Bureau, Technical Services and Special Investigation Section	29
5.3	Organization Chart - Bay Area Air Pollution Control District	30
5.4	Current Organization Chart - Bay Area APCD, Engineering Section	31
5.5	Organization Chart - City of Chicago Department of Environmental Control	32
5.6	Current Organization Chart - City of Chicago Dept. of Environmental Control Technical Services Division	33
5.7	Request for Source Test or Sample Analysis - Form Used in Los Angeles	41
5.8	Automated Source Test Request Form - State of New Jersey	43
6.1	Pre-Survey Form for Combustion Sources	46
6.2	Pre-Survey Form for Incinerators	48
6.3	Pre-Survey Form for Industrial Process	49
7.1	Number of Test Points	55
7.2	Cross-Section of a Circular Flue Divided into Three Concentric Equal Areas, Showing Location of Sampling Points	56
7.3	Cross-Section of Rectangular Flue Divided into Twelve Equal Areas With Sampling Points Located at the Center of Each Area	56
7.4	Pitot Tubes Usually Used to Measure Velocity Head	58

LIST OF FIGURES

Figure		Page
7.5	Gas Velocity and Volume Data	62
7.6	Correction Factor Nomograph	71
7.7	Operating Nomograph	72
7.8	Expected Errors Incurred by Non-Isokinetic Sampling	75
7.9	Particulate Sampling Train Used By Office of Air Programs	78
7.10	Particulate Field Sampling Meter Data	86
7.11	Boiler Operating Data	88
7.12	Incinerator Operating Data	89
7.13	Process Operating Data	91
7.14	Particulate Analysis Data	96
7.15	Format for Presenting Emissions from Fuel Combustion Units	100
7.16	Summary of Emission Test Data	101
7.17	Particulate Sampling Calculations	104
A1	Correction Nomograph for Use With Figure A2	116
A2	Operating Nomograph	117
C1	Orifice Calibration Form	122

LIST OF TABLES

Table		Page
5.1	Examples of Source Sampling Staffs of Various Agencies	35
5.2	Relative Pay Scales of Technical Personnel By Region	37
5.3	Space Requirements for Source Sampling Programs	39
7.1	Percent of Circular Stack Diameter From Inside Wall to Traverse Point	57
7.2	Example Determination of Type S Pitot Tube Correction Factor	59
7.3	Typical Format for Test Report	97

INTRODUCTION

This manual is provided as a service by the Division of Applied Technology, Office of Air Programs, Environmental Protection Agency to assist state and local air pollution control agencies to better understand the purposes and procedures of source sampling. Presented in this booklet are, general guidelines to show how source sampling can be part of an agency's program, the organization and approximate cost of such a program; regulations required to permit source sampling, a detailed description of the Office of Air Program's procedure for particulate sampling; and other related material.

Organizational structures and functional duties of the source sampling group cannot be exactly defined since this will vary with the overall structure of the control agency. Example organization charts and functions are however presented. Sampling and analysis procedures can likewise not be exactly defined for all cases since these will vary with the purpose of the test and the process sampled. Procedures currently used by the Office of Air Programs are however presented, and should be followed in order to obtain comparable results.

1.0 SOURCE SAMPLING PURPOSES

Source sampling or emission testing, as applied to air pollution studies, is the procedure whereby a representative sample is removed from some larger, contaminant bearing gas stream confined in a duct or stack. This sample is then subjected to further analysis and the contaminant concentrations are related to the parent gas stream to determine total quantities. Since the sample extracted from the main gas stream usually represents a very small fraction of the total volume, extreme care is required in obtaining a representative sample. Due to the many and variable factors encountered in sampling gas streams, complex methods must frequently be used to obtain these representative samples.

Source sampling, frequently answers a variety of questions, the main one being - what are the quantities and concentrations of emissions? Subsequent questions which can be answered from this basic determination include:

1. Is the process in compliance with present or expected emission regulations?
2. What is efficiency of existing pollution control equipment?
3. What effect do various process variables have on emissions?
4. Is a valuable product or by-product being emitted?
5. What are the potential (uncontrolled) emissions of various processes?

2.0 FUNCTIONS OF THE SOURCE SAMPLING UNIT[a]

The primary function of the source sampling unit is to obtain reliable emission data. The exact duties assigned to the source sampling unit to perform this function will vary widely from agency to agency depending on the potential work load for this unit, the emission regulations, and the availability of other agency personnel when required. In small agencies, where source sampling may not be a full-time activity, source sampling personnel may actually be part of some other unit such as engineering or technical services. In this case, when sampling is required, personnel will have to reschedule their other work, perform the test work and analysis, and then return to their routine duties.

In contrast to this part-time activity, a large agency with many requirements for source testing will have a full-time staff performing tests. This staff will include chemists as well. Engineering technicians can maintain the sampling equipment, perform calibrations, assist in stack testing, and make routine calculations. The engineering staff will perform sampling site surveys, plan the test procedures, set the schedule, supervise the actual tests, review calculations, and prepare the final report. In large source sampling units, a chemist or senior chemical technician may be assigned to the sampling group. This person would be responsible for all routine lab analysis and serve as coordinator between the laboratory and sampling units.

---

a) For simplicity, the group of people comprising the source sampling function are referred to as a unit. They could be referred to as a section, group, etc., depending on the agency's administrative breakdown.

The stack sampling unit can also perform duties closely related to source sampling, such as determining or checking emission factors for various processes, developing and/or improving test methods and equipment, developing particle size distribution data, and preparing summary reports of emission data and related factors for presentation at technical meetings.

Section 5.0 presents organizational plans and personnel assignments for various types of control agencies.

2.1 Specific Duties Assigned to the Source Sampling Unit

Specific duties to be performed by the source sampling unit in a larger agency include:

Technical Duties

1) Develop and up-date reliable source testing procedures for particulate and gaseous emissions*
2) Calibrate and maintain all equipment
3) Plan and conduct source tests as required
4) Perform and check all test calculations
5) Prepare test reports and summaries of emission data
6) Review source tests conducted by private firms

Administrative Duties

1) Train personnel
2) Procure equipment to conduct source tests
3) Maintain a file of all source test data
4) Prepare annual reports and budget requirements

---

*) All methods used for compliance tests are subject to approval by the Office of Air Programs

5) Make contacts with plant personnel
6) Schedule tests
7) Coordinate source test data with other agency activities

The functions assigned to the source sampling group in a small agency are more varied since other duties will be performed in the interim between conducting source tests.

In addition to the technical duties connected with source sampling, the following additional duties for example can be performed:

1) Conduct a limited ambient air monitoring program
2) Conduct emission inventories
3) Assist in plan review and site inspections
4) Perform routine laboratory analyses

Some of the engineering and administrative functions may be assumed by higher levels of supervision in smaller agencies. Alternatively the entire sampling function can be contracted out to a reliable consultant with the administrative duties handled by the agency.

3.0 REGULATIONS REQUIRED TO CONDUCT SOURCE SAMPLING

3.1 Statutory Authorization to Establish Program

Air Pollution control agencies possess only those powers specified by the legislative body through some type of enabling legislation. Generally two steps are required before the agency can embark on a source sampling program, namely: 1) enabling legislation is adopted and 2) regulations are promulgated. The enabling legislation should establish that the air pollution control agency is empowered to maintain a source testing program. The regulations detail the program and refer to the test procedures, testing requirements, test frequencies, emission limits, and the like.

3.1.1 State Programs

Most state air pollution control agencies have authority to inspect processes and equipment to determine compliance with equipment specifications and emission regulations. However, a deficiency may exist where inspection powers are granted without specific mention of the administration of a testing program. In the absence of specific language authorizing source sampling, it is possible that the statute is sufficiently broad to reasonably infer that a testing program is to be implemented. Perhaps such an inference may be drawn from the stated purpose of the legislative power-grant. However, to guard against possible misinterpretations, enabling legislation should specifically mention inspection powers and source sampling administration. The Federal Clean Air Act of 1970 requires that a state have authority to make inspections and test emissions. A source sampling program is essential to the enforcement aspects of an implementation plan.

After legal advice has been obtained as to the adequacy of the enabling legislation, the state agency should develop administrative regulations consistent with the legislation. While there are many existing regulations upon which administrative regulations can be based there is no substitute for the assistance of legal counsel at the outset. He can, however, benefit from a study of existing regulations, and they should not be ignored.

3.1.2 Local Programs

Many states have delegated to their various political subdivisions the authority to establish and maintain air pollution control programs. The Federal Clean Air Act however specifies that the primary responsibility for controlling air pollution lies with the states. When a state does delegate this authority, it must be ready to step in if the local entity fails to meet its obligations. For local programs, the specific entity - usually a county or health district - has to adopt emission source sampling regulations. Local regulations must be no less stringent than the state's regulations. As with the state agency, the local political subdivision must determine that it has adequate authority to establish a source sampling program and then adopt compatible regulations or ordinances.

In some states it may not be necessary for the state legislature to sanction local programs. That is, in the absence of statutory authority it may be possible to establish and maintain a source sampling program through the powers given to or retained by various state political subdivisions under the state constitution. Thus, various cities may maintain programs on the basis of their constitutionally granted home-rule powers. As previously stated, local program regulations must be no less stringent than the state regulations.

3.1.3 Litigation of Source Sampling Regulations

Through 1969, no cases have been reported concerning the litigation of source sampling regulations. However, the related area of search and seizure has been very active since the Supreme Court decision in See v. City of Seattle, 87 S. Ct. 1737 (1967). Search warrant requirements are discussed in Section 3.3

3.2 Regulations Requiring Source Sampling and Monitoring

State regulations requiring periodic reports on the nature and amount of emissions, and the installation of emission monitoring equipment are mandated by the Clean Air Act as amended in 1970 [Sec. 110(a) (2) (F)]. The Act, as amended, also provides the Administrator of EPA with authority to promulgate regulations regarding the periodic testing and monitoring of emissions by the owner or operator of any stationary source. [Sec. 114(a)]. Authority also exists for the Administrator to conduct source tests under certain conditions. [Sec. 114(a) (2) (B)]. Basically, both the regulators and the regulated will conduct source tests.

3.2.1 Tests by the Agency

While the primary responsibility for source testing

ing rests with the process owner, the agency must have authority to conduct its own tests as a back-up measure. The Agency's regulations should consider the following:

- Test Methods - Standardized testing methods are required. Regulations should specify that tests will be conducted in a manner determined by the director of the Agency. These methods in turn should be approved by the Office of Air Programs.
- Equipment and Processes to be Sampled - Regulations should specify that all stationary sources are subject to being tested by the Agency.
- Frequency of Tests - The director of the Agency should have the discretion to require source tests. Provisions should be made for testing when the agency has good cause to suspect emissions in excess of the regulatory limitations as determined by field inspections.
- Employment of Independent Testers - It may be desirable to provide for the employment of qualified independent testers. This is especially pertinent to the smaller agencies.
- Access to Facilities - Sampling ports, electrical power, platforms, ladders, and the like are all necessary for source sampling. These facilities should be provided at the Owner's expense and should be specified for all operations subject to the source sampling requirements. Reasonable access to the test facilities should also be specified. Installation of these facilities can be incorporated in a permit system.
- Test Costs - Regulations should specify an equitable allocation of costs. A general guideline might be to require full payment by the Owner-Operator in all cases where the test indicates emissions are in excess of the regulatory limitations and where the test is being conducted pursuant to the issuance of the first operation permit. Where emissions are below the regulatory

limit, the Owner-Operator would not be charged.

3.2.2 Tests by the Owner-Operator

The Owner-Operator will be required to conduct tests pursuant to state and Federal regulations. The following items should be considered in preparing regulations:

- ° Frequency of Tests - Tests should be made to provide the Agency with information regarding the nature, extent, and quantity of emissions. After the initial test, the Agency should be given the discretion to require additional tests.
- ° Test Certification - All tests should be certified by a professional engineer or witnessed by an agency representative.
- ° Test Costs - The Owner-Operator should bear all costs incurred in making his own tests.
- ° Test Methods - Standardized testing methods should be required. Regulations should specify that tests must be conducted in a manner determined by the director of the agency.

3.3 Search Warrants

The necessity for the procurement of a search warrant as a condition precedent to source sampling must be considered in preparing a regulation. This is a very fluid area at present. Leading cases in this area are See v. City of Seattle, 87 S.Ct. 1737 (1967); People v. White, 65 Cal. Rptr.923 (1968); United States v. Kramer Grocery Co., 418 F. 2d 987 (1969); and Colonnade Catering Corp. v. United States, 25 L Ed 2d 60 (1970).

The decision to design a regulation which will alleviate the need for search warrants is up to the agency. Such a regulation will require the advice of the agency's legal counsel and should consider the following factors:

- ° The entrance, inspection and testing should be connected to a bone fide licensing or permit system.
- ° Penalty provisions should not be designed so as to indicate that they are the sole sanction, without a warrant, to enter.
- ° Consent to test should be obtained in advance with the issuance of the license or permit.

3.4 Typical Statutes, Codes and Regulations

Typical statutes and regulations promulgated in jurisdictions which have established air pollution control agencies are presented in this Section to show how the various factors discussed in the first three Sections of this chapter may be integrated into statutes, codes, and regulations. These statutes and regulations cover state statutes, regulations of state agencies, and regulations of local agencies, all of which pertain to source sampling.

3.4.1 State Statutes

The enabling legislation of the State of Ohio (ORC §3704.03) reads as follows:

> **Sec. 3704.03 Powers of board.**
> The air pollution control board may:
> (K) Through any individual member or any representative authorized by the board, enter upon private or public property, including improvements thereon, at any reasonable time for the purpose of determining if there are any emissions from such premises, and if so, to determine the sources and extent of such emissions;

◁—— Entry by the board, an authorized employee, or consultant

◁—— Source sampling

The New Jersey law (N.J.S.A. §26:2c-9) provides:

> The department shall control air pollution in accordance with the provisions of any applicable code, rule or regulation promulgated by the department and for this purpose shall have power to—
>
> (d) Enter and inspect any building or place, except private residences, for the purpose of investigating an actual or suspected source of air pollution and ascertaining compliance or noncompliance with any code, rules and regulations of the department. Any information relating to secret processes or methods of manufacture or production obtained in the course of such inspection, investigation or determination, shall be kept confidential and shall not be admissible in evidence in any court or in any other proceeding except before the department as herein defined. If samples are taken for analysis, a duplicate of the analytical report shall be furnished promptly to the person suspected of causing air pollution;

◁—— Promulgation of regulations

◁—— Source sampling

The Kentucky law (KRS §224.370) reads:

> **224.370 Inspection of premises; interference unlawful.** Any duly authorized officer, employe, or representative of the commission may enter and inspect any property, premise, or place at any reasonable time for the purpose of investigating either an actual or suspected source of air pollution or of ascertaining the state of compliance with KRS 224.310 to 224.460 and 224.991 and regulations enforced pursuant thereto. No person shall refuse entry or access to any authorized representative of the commission who requests entry for purposes of inspection, and who presents appropriate credentials; nor shall any person obstruct, hamper, or interfere with any such inspection. (1966, c. 22, § 9)

◁— Entry by the commission, an authorized employee, on consultant

◁— Source sampling

Illinois has just passed a comprehensive Environmental Protection Act. Section 10 of that Act reads in part:

> Section 10. The Board, pursuant to procedures prescribed in Title VII of this Act, may adopt regulations to promote the purposes of this Title. Without limiting the generality of this authority, such regulations may among other things prescribe;
>
> (f) Requirements and procedures for the inspection of any equipment, facility, vehicle, vessel, or aircraft that may cause or contribute to air pollution;

◁——— Adoption of regulations including broad power for inspection

3.4.2 Regulations of State and Local Agencies

The Commonwealth of Kentucky Air Pollution Control Commission has adopted the following testing requirements for indirect heat exchangers in the commission's Regulation 7:

(1) Whenever the Kentucky Air Pollution Control Commission has reason to believe that the emission limits of this Regulation are being violated, it may require the owner to conduct or have conducted at the owner's expense, tests to determine the particulate matter emission level, which tests shall include stack tests if circumstances so demand. The Kentucky Air Pollution Control Commission may request that such tests be conducted in the presence of Commission representatives.	◁— Frequency of tests ◁— Costs of test ◁— Certification of test
(2) Should the Kentucky Air Pollution Control Commission wish to conduct tests of its own to determine compliance with emission limits of this Regulation, the owner shall provide at no expense to the Kentucky Air Pollution Control Commission, reasonable and necessary openings in stacks, vents, and ducts, along with safe and easy access thereto including a suitable power source to the point of testing.	◁— Tests by state agency ◁— Test facilities and access
(3) The Kentucky Air Pollution Control Commission shall be supplied with such data as it may require to establish test conditions.	
(4) Stack tests for particulate matter shall be made by methods found in ASME "Power Test Code PTC 27," dated 1957, titled, "Test Code for Determining Dust Concentrations in Gas Streams" or by such other methods approved by the Kentucky Air Pollution Control Commission.	◁— Test procedures (Should be updated) ◁— Variance of procedure at discretion of Agency

Kentucky's Regulation 8, Section 6, also provides for source testing as a condition of the issuance of a use permit.

> Permits issued hereunder shall be subject to such terms and conditions set forth and embodied in the permit as the Commission shall deem necessary to insure compliance with its standards. Such terms and conditions may include maintenance and availability of records relating to operations which may cause or contribute to air pollution including periodic source or stack sampling of the air contaminant sources.
>
> Acceptance of a permit conditioned as described herein shall denote agreement to the restrictions embodied in the permit and shall thenceforth be binding upon the holder of the permit.

◁— Periodic sampling by licensee

◁— Consent to inspect and test

The City of Chicago Ordinance 17-2.52 provides a comprehensive testing regulation:

> **17-2.52** The commissioner is hereby authorized to conduct or cause to be conducted, any test or tests as may be necessary to determine the extent of emission of particulate matter from any fuel-burning, combustion or process equipment or device, if and when, in his judgment, there is evidence that any such equipment, process or device is exceeding any emission limitation prescribed by or under this chapter. The result of any test shall be made available to the person responsible for such property tested. Tests shall be made and the results calculated in accordance, where applicable, with American Society of Mechanical Engineers "Power Test Codes, Test code for determining dust concentration in a gas stream PTC-27-1957" procedure as revised from time to time or in accordance with modified procedures mutually agreed upon be-

◁—— Tests by commissioner, an employee, or consultant

◁—— Equipment to be used

◁—— Frequency of tests

◁—— Test procedures (Should be up-dated)

◁—— Procedures may be modified at commissioner's discretion with Owner's approval tween the commissioner and the person. All tests and calculations shall be made under the direction of a competent engineer. Any test or tests to be conducted on the premises where such equipment or device is located shall be made during reasonable hours, after written notice to, and with the cooperation of, the owner or operator. The cost of any test or tests and calculations shall be a debt due the city from any person responsible as owner, operator or otherwise of such fuel-burning, combustion or process equipment or device in all cases when such test or tests shall have proven any emission of particulate matter in violation of any provision of this chapter, and such unpaid debt shall be recoverable in any court of competent jurisdiction. If any such emission is shown by such test or tests to be within the limits of emission prescribed in this chapter, the cost of such test or tests shall be charged to the annual appropriation of the department.

◁—— Owner Cooperation;
Test cost

The City of Cleveland's authority to test is given in Chapter 5 of the Air Pollution Code. Section §4.0502 reads in part:

§4.0502. Duties of Commissioner.

The Commissioner of Air Pollution Control under the supervision and direction of the Director of Public Health and Welfare shall:

F. Make inspections and tests of existing and newly installed equipment subject to this ordinance to determine whether such equipment complies with this code;

Complete details of source sampling requirements are then given in Chapter 17 of the same Code:

§4.1702. Sampling and Testing.

(A) The Commissioner of Air Pollution Control is hereby authorized to conduct, or cause to be conducted, any test or tests of any new or existing process, fuel-burning, refuse-burning, or control equipment the operation of which in his judgment may result in emissions in excess of the limitations contained in this ordinance or when the emissions from any such equipment may exceed the limits of emissions provided for herein. All tests shall be conducted in a manner determined by the Commissioner and a complete detailed test report of such test or tests shall be submitted to him. When tests are taken by the owner or independent testers employed by the owner, the Commissioner shall require that the said tests be conducted by reputable, qualified personnel and shall stipulate that a qualified representative or representatives of the Division of Air Pollution Control be present during the conduct of such tests. The Commissioner may stipulate a reasonable time limit for the completion of such test and the submission of test reports.

◁—— Tests by the Commissioner or authorized representatives

◁—— Test procedures

◁—— Tester qualifications

(B) Nothing in this section concerning tests conducted by and paid for by any person or his authorized agent shall be deemed to abridge the rights of the Commissioner or his representatives to conduct separate or additional tests of any process, fuel-burning, refuse-burning, or control equipment on behalf of the City of Cleveland, whether or not such tests relate to emissions controlled by specific limitations under this code.

§4.1703. Test Facilities and Access.

(A) It shall be the responsibility of the owner or operator of the equipment tested to provide, at his expense, utilities, facilities and reasonable and necessary openings in the system or stack, and safe and easy access thereto, to permit samples and measurements to be taken. All new sources of air contaminants created after the effective date of this ordinance may be required by the Commissioner of Air Pollution Control to provide utilities, facilities and adequate openings in the system or stack, and safe and easy access thereto, to permit measurements and samples to be taken.

◁—— Testing facilities and access

(B) When any process equipment, fuel-burning equipment or refuse-burning equipment has caused an air pollution nuisance, as determined by the Commissioner, or has violated a provision of Chapter 11, 13 or 15 of this code, the Commissioner may, at his discretion require that said equipment be equipped with an air contaminant recording device with an audible alarm set so as to become activated upon reaching prohibited levels of emission, which device shall be maintained in proper operating conditions at all times. Records from such recording device shall be made available to the Commissioner for periods up to one year.

§4.1704. Test Costs.

If emission tests conducted as a result of the action of the Commissioner of Air Pollution Control substantiate that a violation exists, the person or persons responsible for the violation shall be responsible for paying all attendant costs for conducting said tests. If said tests do not show that a violation exists, then the City shall be responsible for paying all costs for conducting the said test. In no event shall the city assume costs of providing facilities, utilities and access for such testing. When the person responsible elects to conduct his own stack emission tests, then the person so electing shall pay for the test or tests notwithstanding other provisions of this section, and irrespective of the result. The costs of emission tests required by the Commissioner on newly installed equipment for the issuance of the initial permit to install and the issuance of the initial certificate of operation shall not be at the expense of the City of Cleveland regardless of results. The tests for existing sources relating to contaminants not specifically controlled by this code shall be at the expense of the City of Cleveland except for facilities, utilities and access required to be provided by this Chapter.

◁— Test costs

◁— Cost of providing test
facilities

◁— Test costs

§4.1705. Circumvention and Right of Entry.

(A) No person shall build, erect, install, or use any article, machine, equipment, or other contrivance, the sole purpose of which is to dilute or conceal an emission without resulting in a reduction in the total release of air contaminants to the atmosphere nor shall a person do any thing nor commit any act with the intent to distort stack test emission results.

(B) Any person who in any manner hinders, obstructs, delays, resists, prevents, or in any manner interferes or attempts to interfere with the Commissioner or his representatives in the performance of any duty enjoined, or shall refuse to permit the Commissioner or such representatives to perform their duty by refusing them, or either of them, entrance at reasonable hours to any premises in which the provisions of this ordinance are being violated, or are suspected of being violated, or refuse to permit testing, or permit the inspection or examination of such premises for the purpose of the enforcement of this ordinance shall be subject to cancellation of the certificate of operation, or such other action as may be provided at law or by provisions of this code.

4.0 LEGAL USE OF SOURCE SAMPLING INFORMATION

Every test should be conducted as if it will ultimately be used as evidence in court. The collection and analysis of source samples should become a routine matter to the agency personnel involved. However, it must be remembered that this routine procedure is esoteric to the layman and therefore subject to greater scrutiny whenever the agency has to rely on these results. It is imperative that source sampling and analysis be done under standard procedures and that each step be well documented. In short, the report may ultimately be subjected to the requirements of the Rules of Evidence.

This chapter will discuss the standardization of source sampling procedures relative to taking the sample, chain of custody, laboratory analysis, report custody, and disposition of the original work sheets.

4.1 Taking the Sample

In attacking the validity of source sampling results, the adverse party will concentrate on four main items relative to taking the sample: 1) The sampling procedure, 2) The recorded data and calculations, 3) The test equipment, and 4) The qualifications of the test personnel.

The agency must keep in mind the possibility of adverse inferences that may arise from the use of unorthodox or new procedures. Therefore deviations from the standard procedure must be kept to a minimum and applied only where absolutely necessary to obtain an accurate sample. Changes in methodology must be based on sound engineering judgment and must be carefully documented. Standard procedures which should receive particular attention are:

1) Location of sampling station
2) Number and size of sampling zones in the duct
3) Use of recommended sampling equipment
4) Careful determination of gas velocities
5) Maintenance of isokinetic sampling conditions
6) Proper handling of the collected sample and recording of container and filter numbers.

Close scrutiny is also focused upon the recorded field data since it is these data which form part of the physical evidence. Standardized forms should be utilized to insure that there is no lack of necessary information. Example forms designed for this purpose are included in Chapter 7. These forms consist of field forms, laboratory forms, and calculation forms. Only the field forms are utilized when taking the sample. This form is designed to clearly identify the process tested, the date and time, location of test station, sampling personnel, and the person who recorded the data. During the actual test period, the meter readings, temperature readings, and other pertinent data should be recorded in the provided spaces immediately upon observation. These data determine the accuracy of the test, and should not be erased or altered. Any errors should be crossed out with a single line and the correct value recorded above the crossed-out number.

4.1.1 Test Equipment

Faulty test equipment can also invalidate a test. In general there are two types of field test equipment, the gas sampling equipment and process measuring equipment.

The process measuring equipment consists of any of the metering devices from which test data is obtained. These are scales for weighing fuel or raw materials, orifices and gages for measuring product flow, and the like. It cannot be assumed that these devices are accurate since proper maintenance and calibration procedures are often lacking. In any case check and record the date on which the device was serviced.

Ideally, the use of process measuring equipment should be kept to a minimum. However, process weight regulations may frequently require the use of such equipment - especially scales. Such scales can only be properly serviced and calibrated by specially trained personnel. The scale manufacturer most generally provides this service. A stamp affixed to the scale by the service crew as a standard procedure will note the date of calibration or inspection. If the scale has not been recently calibrated an engineering judgment must be made concerning its accuracy. A material balance will sometimes provide a check on scale readings.

Other equipment such as flow meters and gages should be properly maintained and used. If there is reason to believe that the equipment is defective, note the reason on the Field Data Form and make an engineering judgment on the validity of the data.

Among gas sampling equipment which requires maintenance and calibration is the Pitot tube, manometers, thermometers, flow meters, and dry gas meter. The maintenance of these instruments is subject to even greater scrutiny in court. Therefore written maintenance records must be kept. Suggested maintenance procedures are as follows:

> Pitot tube - The Pitot tube should be calibrated when acquired. Subsequent calibration is not required but a visual check should be made and noted prior to each test series. (See Section 7.1.2)
>
> Manometers - The inside of the tubes are subjected to the flue gas and the specific gravity of the oil may change due to evaporation. Readings also become difficult as dirt coats the glass tube. It is suggested that the manometers be washed with soapy water and the oil replaced after approximately every sixth test series. Note that the specified oil must be used.
>
> Thermometers - Dial type thermometers are frequently used in the field. These are easily damaged and therefore should be checked prior to each test series. The check should be made against a mercury thermometer at approximately 1/4 and 3/4 of full scale. Thermocouples and associated recording equipment must also be periodically calibrated. Six month intervals are recommended as a minimum.
>
> Dry Gas Meter - The meter should be calibrated prior to each test series. This high frequency of calibration is recommended due to the relatively severe conditions under which the meter is used. It is subject to being bumped, dropped, vibrated, or even being carried upside down. The best method of testing is with a positive displacement calibrator such as a Bell-type Prover or a calibrated orifice.

4.1.2 Test Personnel

The sample must be taken by experienced personnel. While it is not necessary that the chief of the field team be a professional engineer, he must have special training which qualifies him for source sampling. If the report is used in court, the chief of this field team may be called as a witness. Poor data may be inadmissible as evidence. Therefore the chief of the field team should have previous experience as an aide on field tests, and he should preferably have received special training in source sampling. (Section 5.2 describes personnel duties in greater detail.)

One cannot usually perform a source test alone. Two men are normally required for one test station and a minimum of three are required for two stations. It is often difficult to accurately record the large amount of required data if the team is inadequately manned

4.2 Transportation of the Sample

Of primary importance in transporting the sample to the laboratory is that precautions be made to eliminate the possibility of tampering, accidental destruction, and/or physical and chemical action on the sample.

To reduce the possibility of invalidating the results, all components of the sample must be carefully removed from the sampling train and placed in sealed, non-reactive, numbered containers. The sample should then be delivered to the laboratory for analysis. It is recommended that this be done on the same day as the sample was taken. If this is impractical, all the samples should be placed in a carrying case (preferably locked) in which they are protected from breakage and contamination as well as avoiding the possibility of loss.

4.3 Identification of the Sample

Care must be taken in properly marking the sample for positive identification throughout the test and analysis procedures. The Rules of Evidence require impeccable procedures for identification of samples, the analysis of which is the basis for future evidence. An admission by the lab analyst that he could not be positive whether he analyzed sample No. 6 or sample No. 9, for example, could destroy the validity of the entire report. Positive identification must be provided for the filters and the containers used in any specific test.

4.3.1 Identification of Filters and Containers

Filters should be marked for positive identification. Three digits should insure the unique identification of filters for many years. The ink on the filter must be indelible and unaffected by the gases and temperatures to which it will be subjected. Filters must be marked before taring. If another method of identification is desired by the agency, it should be kept in mind that the means of identification must be positive and must not impair the ability of the filter to function.

Each container should also have a unique identification to preclude the possibility of interchange. The number of the container should be recorded on the analysis data sheet (See Figure 7.14) and thereby associated with the sample throughout the test and analysis.

4.4 Handling and Chain of Custody

In no case should the sample be handled by persons not associated in some way with the task. A good general rule to follow is, "the fewer hands the better", even though a properly sealed sample may pass through a number of hands without affecting its integrity.

It is generally impractical for the analyst to perform the field test. However, the Rules of Evidence require that the prosecution be able to prove the chain of custody of the sample. For this reason each person must be able to remember from whom he received the sample and to whom he delivered it. This requirement is best satisfied by having each recipient sign a receipt or the data sheet for the sample or set of samples. The process owner should also be given a receipt for the collected sample.

4.5 Laboratory Analysis and Calculations

Potential sources of error in the analysis of the sample lie in the analyzing equipment, procedures, documentation of results, and the qualifications of the analyst.

Laboratory equipment, especially the analytical balance, should be subjected to a routine maintenance program just as the field equipment is.

> Analytical Balance - Balances are extremely sensitive and therefore require periodic calibration. It is recommended that calibration be done at least biannually, with Class M weights. A record should be kept.
>
> Reagents - Only reagent grade chemicals should be used. Reagents used in an Orsat or similar gas analyzer should be replaced periodically depending on their use.

As with the field procedures, the laboratory data and calculations must be well-documented. The use of standardized forms is recommended. In all cases the person who performs the analysis and/or calculations should sign the data sheet

4.6 Custody of Final Report and Data

The team chief is responsible for the compilation of the test report under the supervision of a senior engineer who then reviews it for content and technical correctness. The ultimate use of the report as evidence of a violation is the responsibility of the agency's supervisory management. It is that echelon which finally approves the report as a correct representation of the field conditions.

Written documents are, generally speaking, considered to be hearsay and therefore not admissible as evidence without a proper foundation. A proper foundation consists of introducing the report by the principal author(s). Thus the chief of the field team and the laboratory analyst would both be required to lay the foundation for the introduction of the test report as evidence. However, the foundation laying is greatly simplified, though still required, under statutory exceptions to the Hearsay Rule found in the Official Reports as Evidence Acts and Business Records as Evidence Acts which various states have adopted.

The rationale of the Official Reports exception is that it is assumed that a public officer performing a particular duty, performs that duty properly and is under no motive to distort the truth. Basically, the Official Reports exception exists to avoid the necessity and expense of calling as witnesses various persons who may have collaborated in making the records.

To insure the benefit of these statutory exceptions to the Hearsay Rule, the source test reports should be filed in a safe place by a file custodian who has responsibility for the files. Once the report is approved, a summary copy is sent to the requestor for further disposition. Generally, the field notes and calculations need not be included in the summary report. However all this material may be required at a future date to bolster the acceptability and credibility of the report as evidence in an enforcement proceeding. Therefore the full report including all original notes and calculation sheets should be kept in the file. Signed receipts for all samples should also be filed with the test data.

Public records are subject to the Best Evidence Rule which basically states that the original of a document is the best evidence and therefore a mere copy is not admissible as evidence. Microfilm, snap-out carbon copies and similar contemporary business methods of producing copies are acceptable in many jurisdictions if the original is not reasonably available, its unavailability is adequately explained, and the copy was made in the ordinary course of business.

5.0 ORGANIZATION AND ADMINISTRATION OF A SOURCE SAMPLING UNIT

5.1 Organizational Plans

The source sampling unit must fit into the agency's organization such that it meets both the needs and available resources of the control agency. Since these parameters vary so widely from area to area, it is impossible to define an ideal overall organizational structure. However the main variables in the organization of source sampling operations are the number and complexity of the process which must be tested and the functions to be performed by the unit.[a]

Structuring the agency's source sampling operations requires considerations of so many variables that no one type of organization can be recommended. Figures 5.1 thru 5.6 show the structure of three agencies which have established, comprehensive source sampling programs. These figures are presented as examples to show how the test program relates to the overall program, and to show the actual organization of the source sampling unit.

Where many diverse, well defined processes are located within an agency's jurisdiction, it is frequently advisable to utilize personnel who have expertise in these specific processes as supervisors of the source test teams. The number and designation of the supervisors will, of course, depend on the processes to be sampled. Unless an extreme amount of specialized testing is required, all purpose teams are more efficient.

---

a) See Chapter 2.0

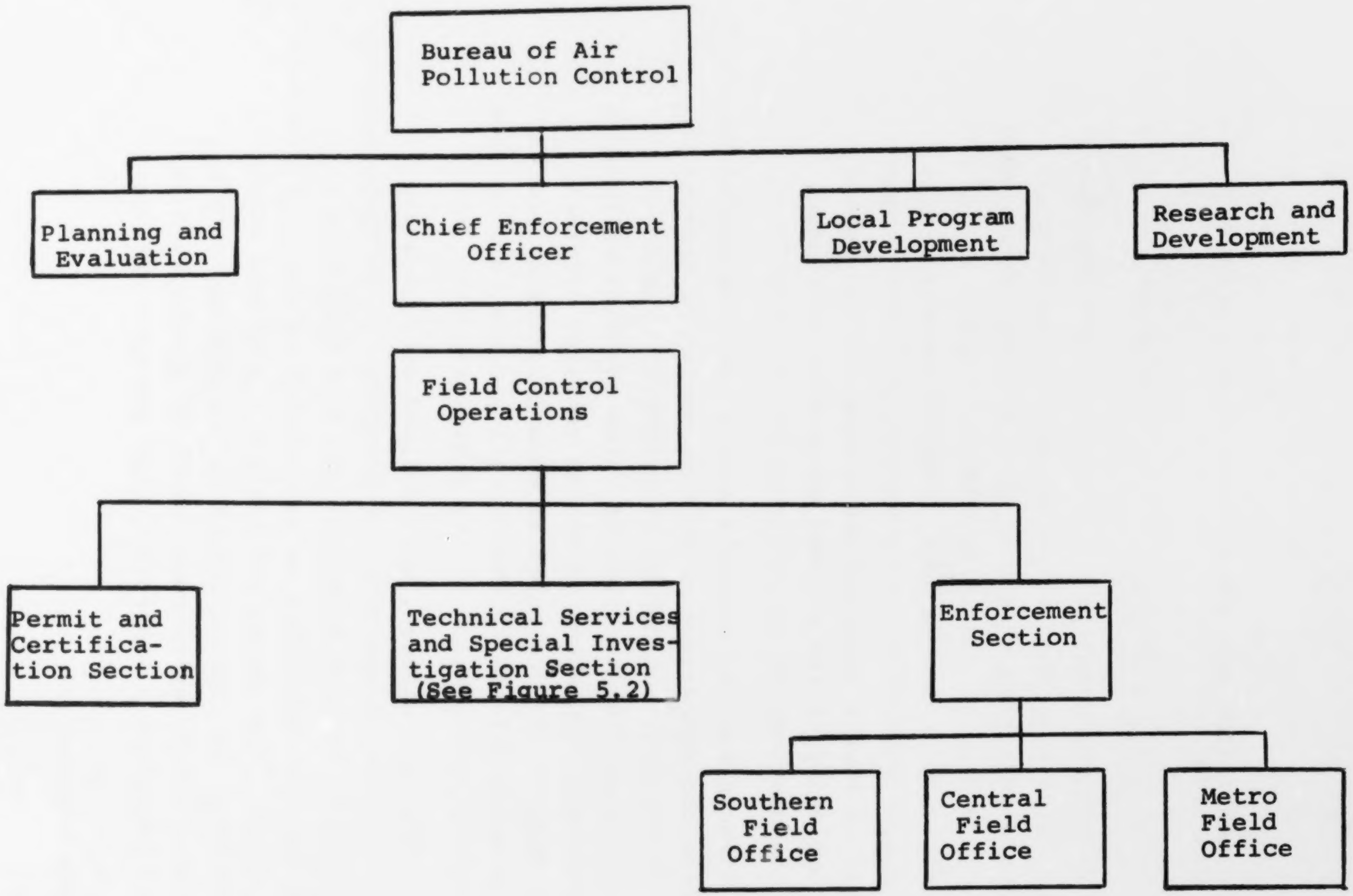

Bureau of Air Pollution Control
Planning and Evaluation
Chief Enforcement Officer
Local Program Development
Research and Development
Field Control Operations
Permit and Certification Section
Technical Services and Special Investigation Section (See Figure 5.2)
Enforcement Section
Southern Field Office
Central Field Office
Metro Field Office

Figure 5.1 Organization chart - State of New Jersey Bureau of Air Pollution Control.

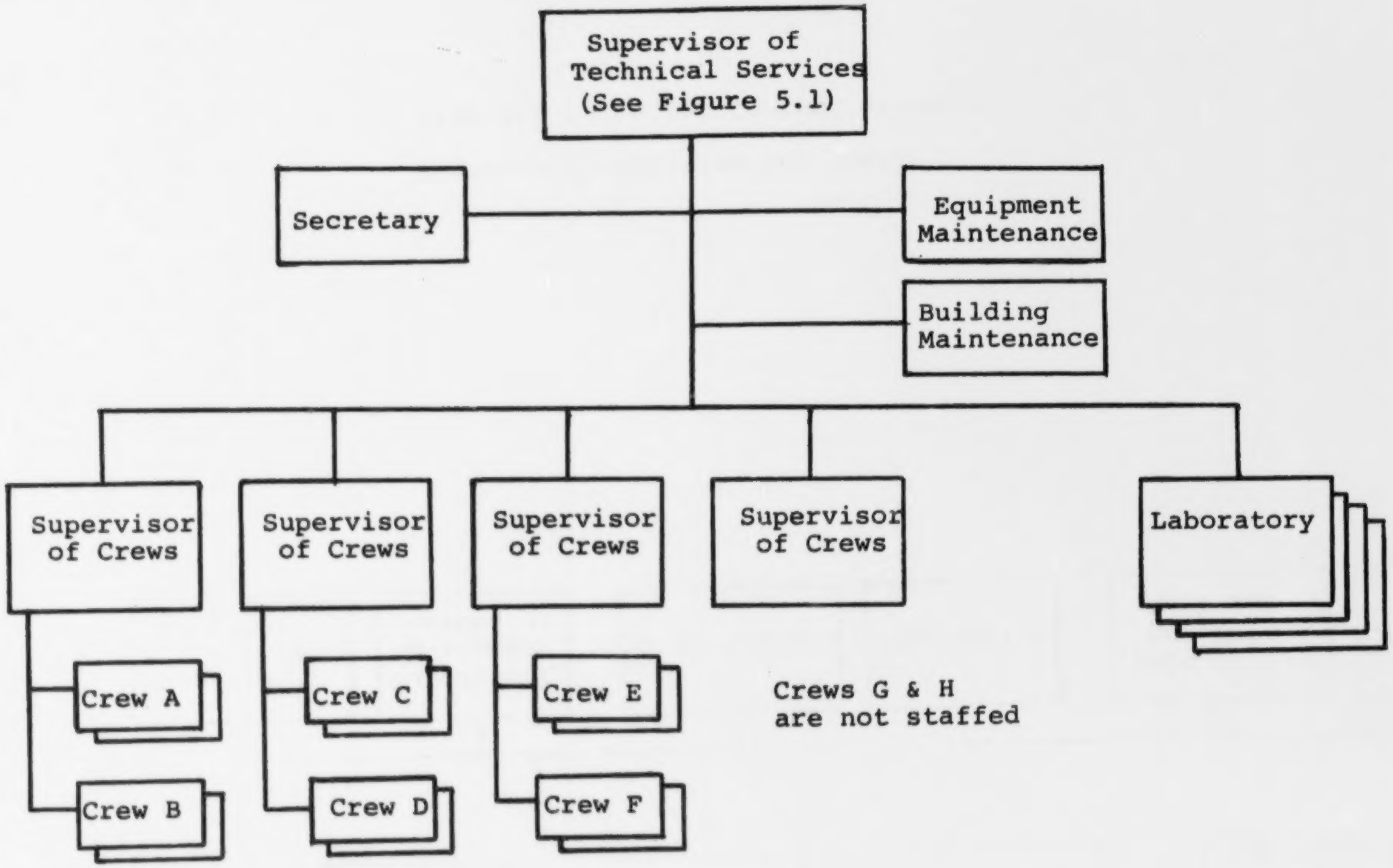

Supervisor of
Technical Services
(See Figure 5.1)
Secretary
Equipment Maintenance
Building Maintenance
Supervisor of Crews
Supervisor of Crews
Supervisor of Crews
Supervisor of Crews
Laboratory
Crew A
Crew B
Crew C
Crew D
Crew E
Crew F
Crews G & H
are not staffed

Figure 5.2 Current organization chart -

State of New Jersey Air Pollution Control Bureau, Technical Services and Special Investigation Section

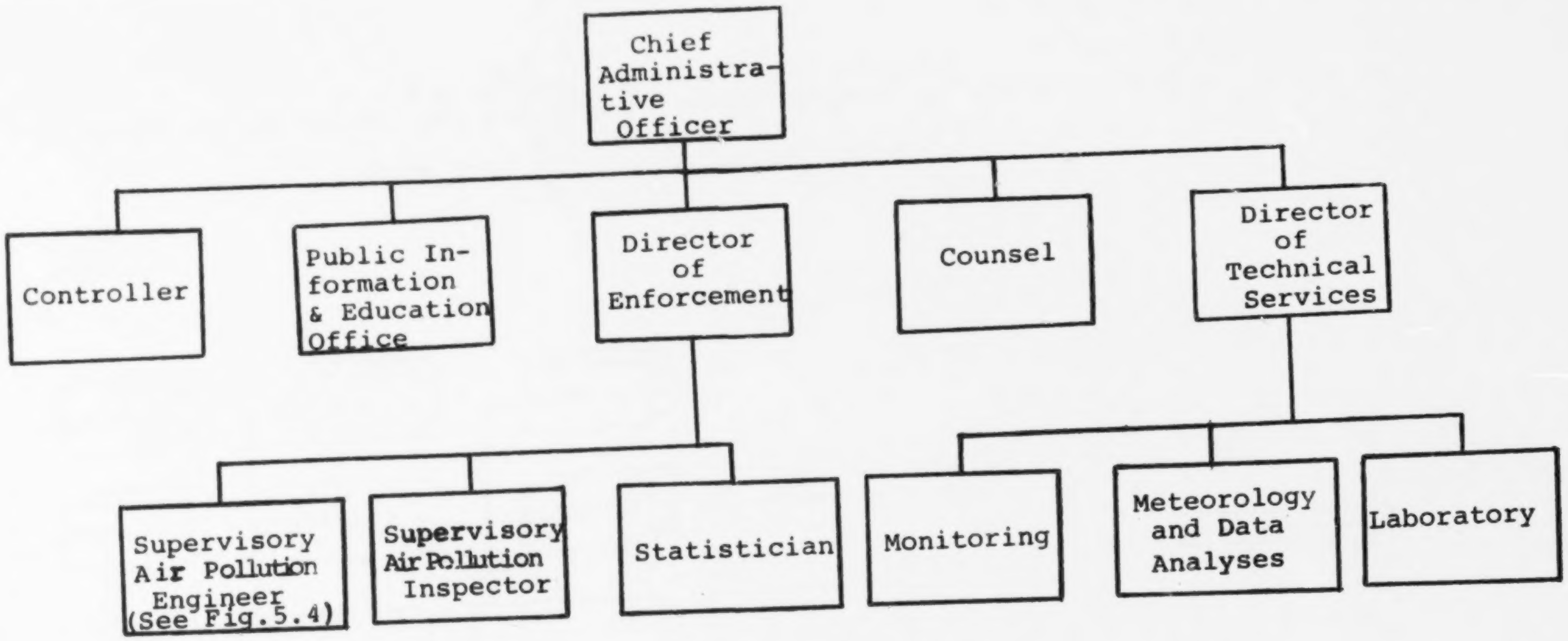

Chief Administrative Officer
Controller
Public Information & Education Office
Director of Enforcement
Counsel
Director of Technical Services
Supervisory Air Pollution Engineer (See Fig.5.4)
Supervisory Air Pollution Inspector
Statistician
Monitoring
Meteorology and Data Analyses
Laboratory

Figure 5.3 Organization chart

Bay Area Air Pollution Control District.

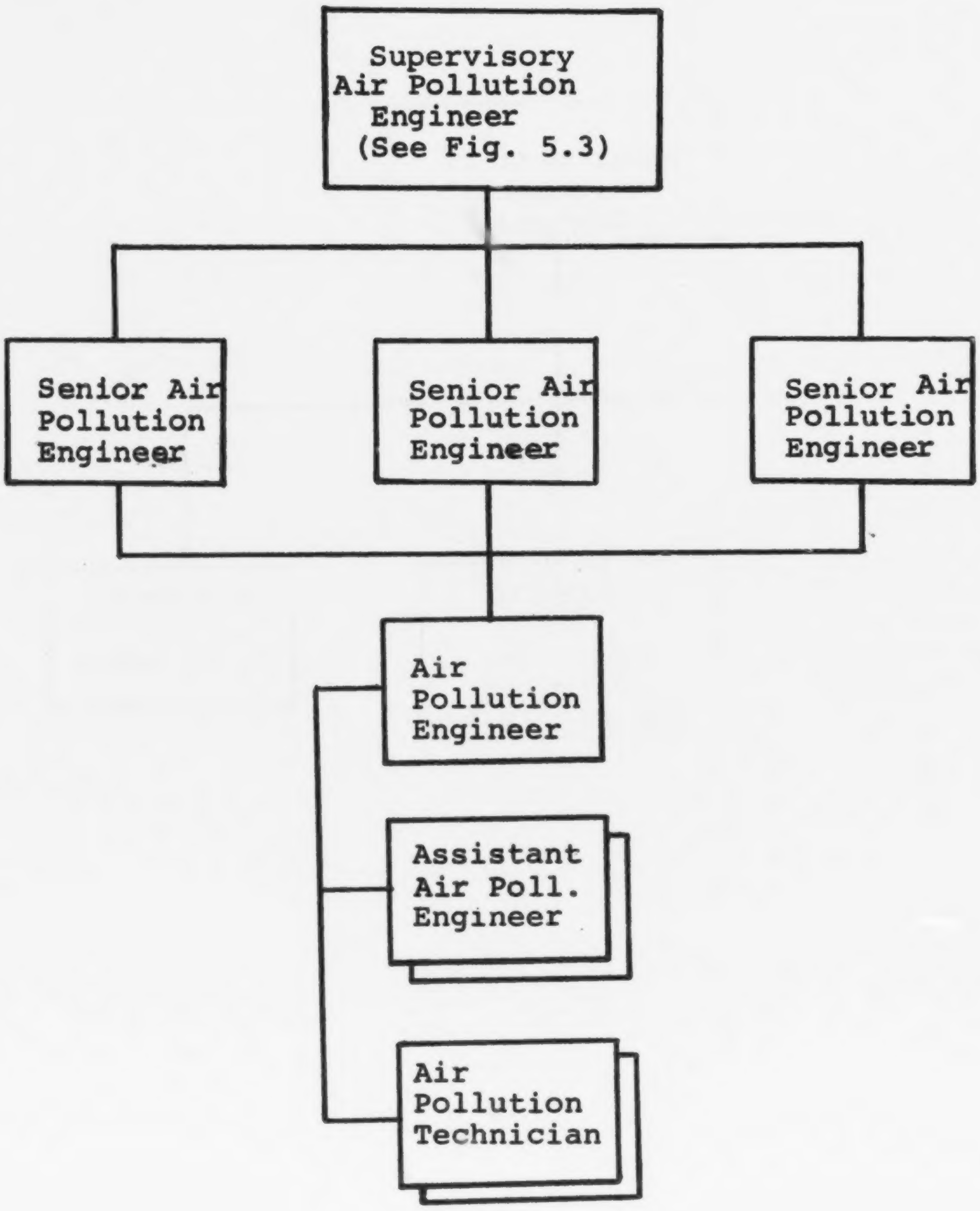

Supervisory Air Pollution Engineer (See Fig. 5.3)
Senior Air Pollution Engineer
Senior Air Pollution Engineer
Senior Air Pollution Engineer
Air Pollution Engineer
Assistant Air Poll. Engineer
Air Pollution Technician

Figure 5.4 Current organization chart Bay Area APCD, Engineering Section.

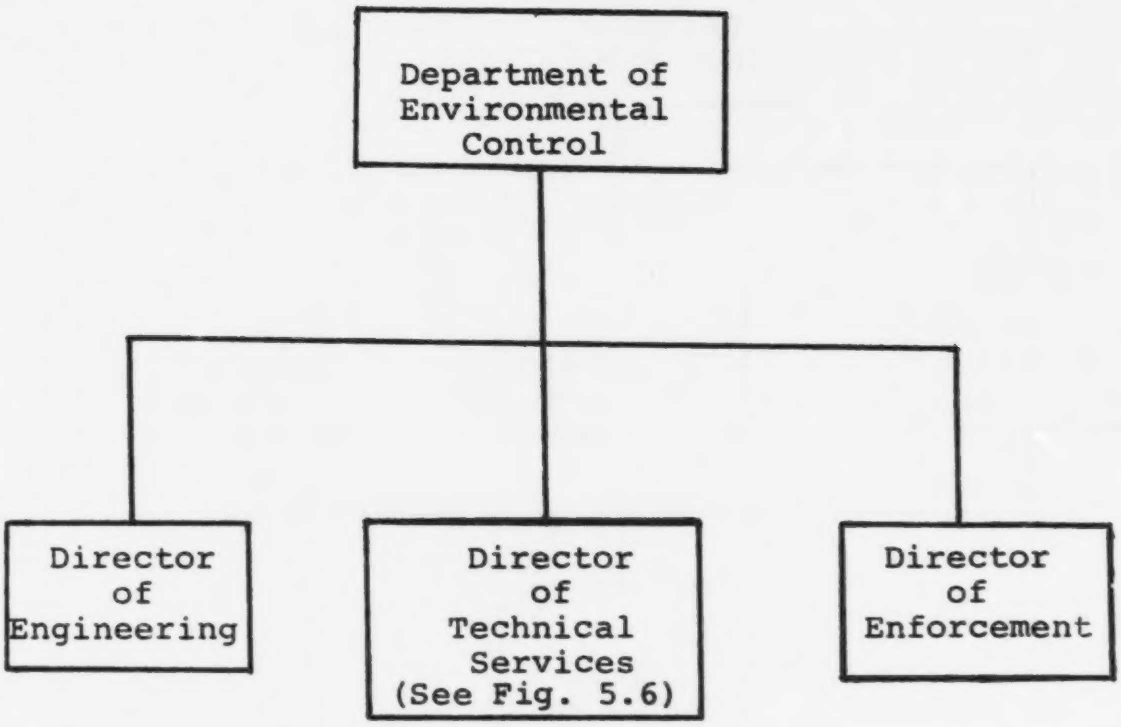

Department of Environmental Control
Director of Engineering
Director of Technical Services (See Fig. 5.6)
Director of Enforcement

Figure 5.5 Organization chart

City of Chicago Department of Environmental Control.

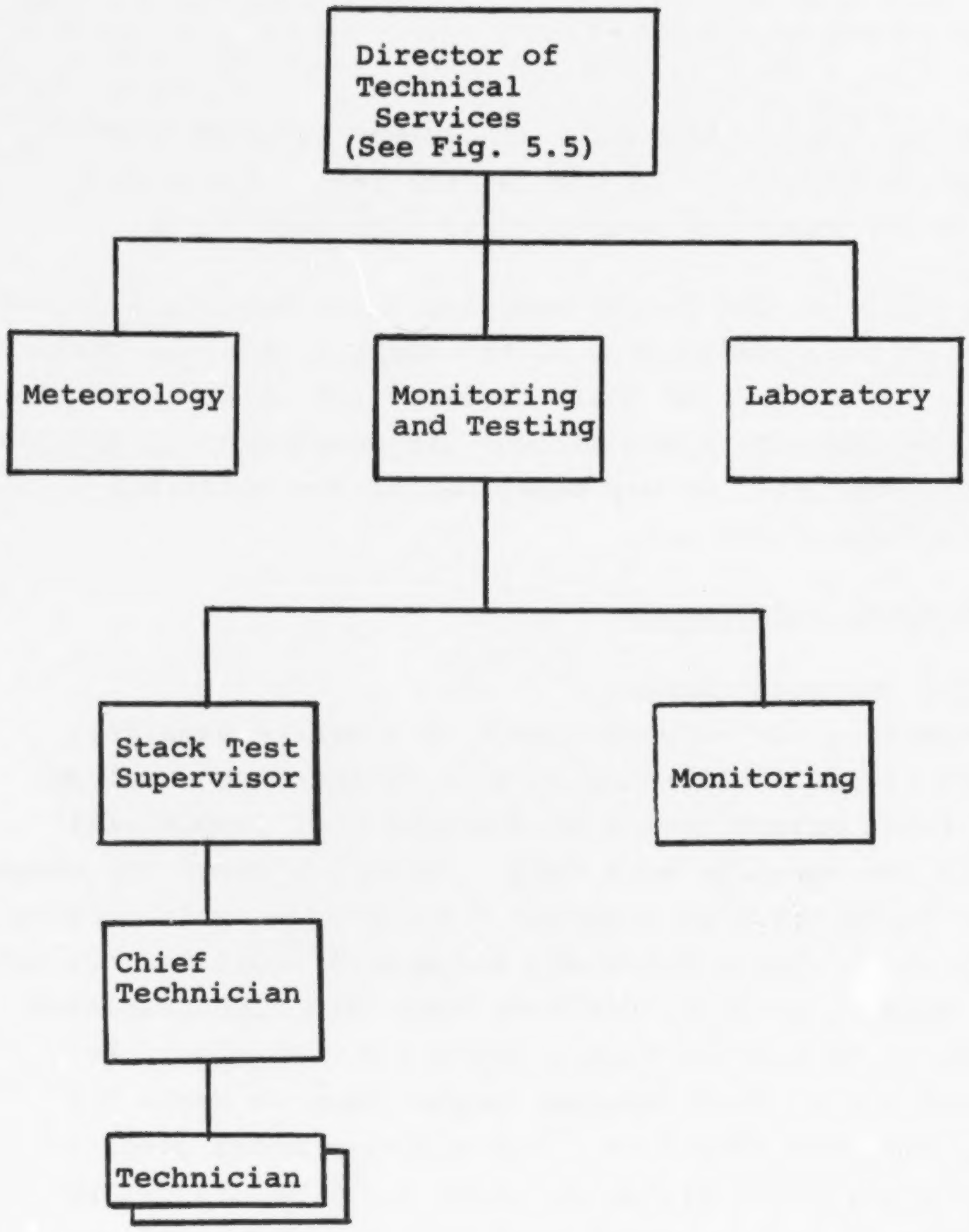

Director of Technical Services (See Fig. 5.5)
Meteorology
Monitoring and Testing
Laboratory
Stack Test Supervisor
Monitoring
Chief Technician
Technician

Figure 5.6 Current organization chart
City of Chicago Dept. of Environmental Control
Technical Services Division.

Since an engineer functionally supervises the test team, his expertise coupled with the testing team's basic background should result in reliable and efficient tests.

The title of the source sampling supervisor will depend on the size and organization of the agency. For the smaller agencies, the supervisor could have several units under him - perhaps the laboratory and ambient air monitoring in addition to source sampling. He may sometimes be the Chief Air Pollution Control Officer.

5.2 Personnel Requirements

5.2.1 Manpower Needs

Estimating the manpower needs of a source sampling operation is difficult since so many factors are involved and the final determination of the number of people will depend on the specific work load. Table 5.1 shows the manpower needs of three existing programs - state-wide, multi-county, and city-wide. Since these are successful programs, the two factors used in a recent manpower model are also displayed in the Table to provide some perspective. It should be noted that the current manpower needs shown in Table 5.1 are compared with 1963 data. The manpower model predicts that an agency must service at least 4,000 manufacturing establishments having annual capital expenditures of over $200 million before more than three source test personnel are required. State-wide capital expenditures of manufacturing establishments during 1967 were less than $200 million in 31 states and less than $400 million in 26 states.

Table 5.1 EXAMPLES OF SOURCE SAMPLING STAFFS OF VARIOUS AGENCIES

Agency	Actual no. of source testing personnel[a]	Number of manufacturing establishments[b]	Annual capital expenditures of manufacturing establishments $\$10^6$
State of New Jersey	4 Team chiefs 12 Technicians[c] (6 teams) 1 Equipment maintenance	15,200	525 (785)[d]
San Francisco Bay Area Air Pollution Control District	3 Sr. engineers 1 Team chief 4 Technicians (2 teams)	6,000	250
City of Chicago	1 Sr. engineer 3 Technicians (1 team)	9,200	230

a) Excludes supervisor, secretary, laboratory, and other personnel not directly related to testing. (1970 data)

b) Source: County and City Data Book, 1967, U.S. Department of Commerce. Reported data is rounded off for purposes of this table; 1963 data.

c) Current plans are for the addition of two more technicians.

d) 1967 data shown for comparison only. Source: U.S. Bureau of the Census, Statistical Abstract of the United States: 1969, Table No. 1110.

The 1970 Amendments to the Clean Air Act however, require greater source test efforts by state and local agencies. Since the manpower model was based on the pre-1970 Act, it may tend to underpredict source testing personnel. This factor should be kept in mind when using the model.

5.2.2 Test Team Personnel

Location and access to the sampling ports determines the size of the basic testing team. In general, two men are required for each sampling station. Agencies currently find that the team chief can adequately supervise two two-man teams testing at different sites. The added work of taking concurrent samples before and after the control equipment may however require a full-time fifth man.

The technicians serving on the test teams should have a basic understanding of source sampling principles. Technicians usually take the sample, record field data, and they may weigh the sample and the filters. Technicians are generally responsible for maintenance and calibration of the test equipment.

The team chief is directly responsible for all the field work and should have a background in engineering or industrial hygiene. In smaller programs, he should be an engineer since he will then report directly to the program supervisor. In general he plans the test, supervises the actual extraction of the sample and may transport the samples to the laboratory. The team chief should check all calculations.

In larger programs, the team chiefs will usually report to a senior engineer. The senior engineer should preferably be a professional engineer having a broad knowledge of the various industrial processes within the agency's jurisdiction. He is responsible for all tests and should be experienced in source sampling and have rapport with process operators. The senior engineer is usually the agency's expert witness in matters involving emission testing.

5.2.3 Personnel Costs

Estimated salary requirements for the various functional positions are presented to indicate the approximate personnel costs of a source sampling program. In all cases ranges are given. The greatest range exists at the technician level to represent the spread between the novice and the experienced technician. Other positions are affected mainly by experience, agency size, and geographical location. Approximate base salary ranges are as follows:[2]

Supervisor	\$15,000 - \$23,500
Senior Engineer	\$13,000 - \$19,500
Team Chief	\$11,000 - \$17,000
Technician	\$ 7,000 - \$13,000
Secretary	\$ 5,000 - \$ 7,000

Overhead rates associated with the base salary must be included for budgeting. In general, the New England and Middle Atlantic regions are areas of highest pay. Table 5.2 lists the various geographic areas with relative salaries based on the New England scale being 100%.

Table 5.2 RELATIVE PAY SCALES OF TECHNICAL PERSONNEL BY REGION[a]

Region	Relative salaries (percent)
New England	100
Middle Atlantic	100
South	92
Midwest	89
Plains	84
Southwest	87
West	92

a) Based on the 1969 survey conducted by the National Society of Professional Engineers.

5.3 Equipment and Space Requirements, and Associated Costs

5.3.1 Equipment and Costs

This section describes the major items of equipment required for a source sampling program. Incidental items such as clamps, heating wire, safety equipment, miscellaneous hardware, and the various pieces of workshop equipment will not be discussed. Section 7.4 presents a detailed discussion of specific equipment needs.

At least two complete sampling trains as described in Section 7.4 are required. These trains include the nozzles and probe, cyclone/filter collector, impingers, pump and meter assembly, and associated equipment. In addition, the agency will minimally require a desiccator and analytical balance for drying and weighing the samples. Provisions must be made for calibrating the dry gas meters. A spirometer or bell-type prover is the best equipment for this purpose. However these devices are very expensive and, whenever possible, arrangements with the local gas utility company for periodic calibration should be made. A carefully calibrated orifice may also be used for calibration. If the regulations require correction to 12% CO_2 or similar basis, an Orsat apparatus will be required.

Each team requires a vehicle for transportation of equipment (a panel truck or station wagon will suffice). In addition, the senior engineer or team chief may require a vehicle for field use.

A complete single set of particulate sampling equipment costs approximately $3,500. Associated laboratory equipment and miscellaneous hardware which can be shared by more than one team costs about $2,000. Associated equipment costs should consider depreciation and maintenance on all equipment, including motor vehicles, used by the program. However such items as office supplies and furnishings are not included herein. Travel costs, personnel overhead, and other administrative costs must of course be figured into the total budget.

5.3.2 Space Requirements and Costs

The source sampling unit requires office and workshop space. Table 5.3 shows the space requirements of three existing groups and shows approximately 70 square feet of shop area per man. Office space is actually determined by administrative policy, and must be considered on a basis of the number of desks. Minimally 50 sq. ft. is required for each desk. Private offices require at least 80 sq. ft. Space costs in leased buildings are on the order of $5 to $6 per square foot per year.

Table 5.3 SPACE REQUIREMENTS FOR SOURCE SAMPLING PROGRAMS[a]

Agency	Personnel[b]	Space allocation, square feet Workshop	 Office
Chicago	5	-	400
Bay Area	9	625	400
New Jersey	18	1200	360

a) 1969 Data.

b) Does not include clerical or laboratory personnel.

5.4 Administrative Procedures

5.4.1 Request for Source Test

Generally, the source testing program exists as a service to the enforcement, engineering, and permit programs. As such, requests for source tests are initiated outside the unit. As a rule the enforcement section will request a test based on information received from its inspectors. The request may also be motivated by the agency's counsel or by citizen complaints especially where visual inspection, both inside and outside the plant, reveals no apparent violation. Tests may also be requested to develop emission factors or for emission inventory purposes. Oftentimes a source test will be requested prior to the issuance of an initial permit to operate.

As programs progress, the source test unit becomes more and more knowledgeable of the individual processes. Therefore, as a practical matter the supervisor of the source sampling unit will influence the decision to test and the priority of the test. After these decisions are made, the senior engineer takes steps to effect the test and determines the type of testing desired.

The form used for requesting a source test should contain such information as is required to determine test methods, priority, purpose, and status of the action requested. Figure 5.7 shows the type of request form used in Los Angeles. In addition to the basic required information, provision is made for special instructions to the tester and for determining the status of the test.

Figure 5.8 illustrates an automated form used by the State of New Jersey. This form also identifies the inspector and provides space for his comments. Status of the file is determined at a glance and a tickler device is incorporated.

Upon completion of the test report, it should be approved by the agency's chief and submitted to the requester.

Figure 5.7 Request for source test or sample analysis - form used in Los Angeles.

SOURCE LOCATION DATA

1. Firm Name ______________________________ Phone No. __________

2. Address ________________________________ City ______________

3. Representative to Contact ____________________ Title _________

REQUEST INITIATION DATA

4. Request Initiated by ____________________ Division ___________

5. Request Approved by _____________________ Date ______________

6. Reason for Request:

☐ Court or Hearing Board Action Case No. ______

☐ Permit Pending Application No. __________

☐ Suspected Violation

☐ ________________________

☐ ________________________

☐ ________________________

SOURCE AND SAMPLE DATA

7. Type of Request: ☐ Source Test ☐ Sample Submitted for Analysis

8. Basic Equipment: (incl. Index Code No.) ______________________

9. Control Equipment: (incl. Index Code No.) ____________________

____

10. Points to be Tested or Description and Source of Each Example Submitted: ____

____

____

____

____

11. Test for Following Constituents:

____________________________ ________________________________

____________________________ ________________________________

____________________________ ________________________________

____________________________ ________________________________

(Continued on Next Page)

Request for source test or sample analysis
(continued)

12. Special Instructions: ______________________________

____

____

____

____

____

ACTION BY SOURCE TESTING UNIT

13. Date Received ______________ Priority ______________

14. Date Sent to Analytical Laboratory ______________

15. Date Report Issued ______________

16. Distribution of Copies ______________

REMARKS

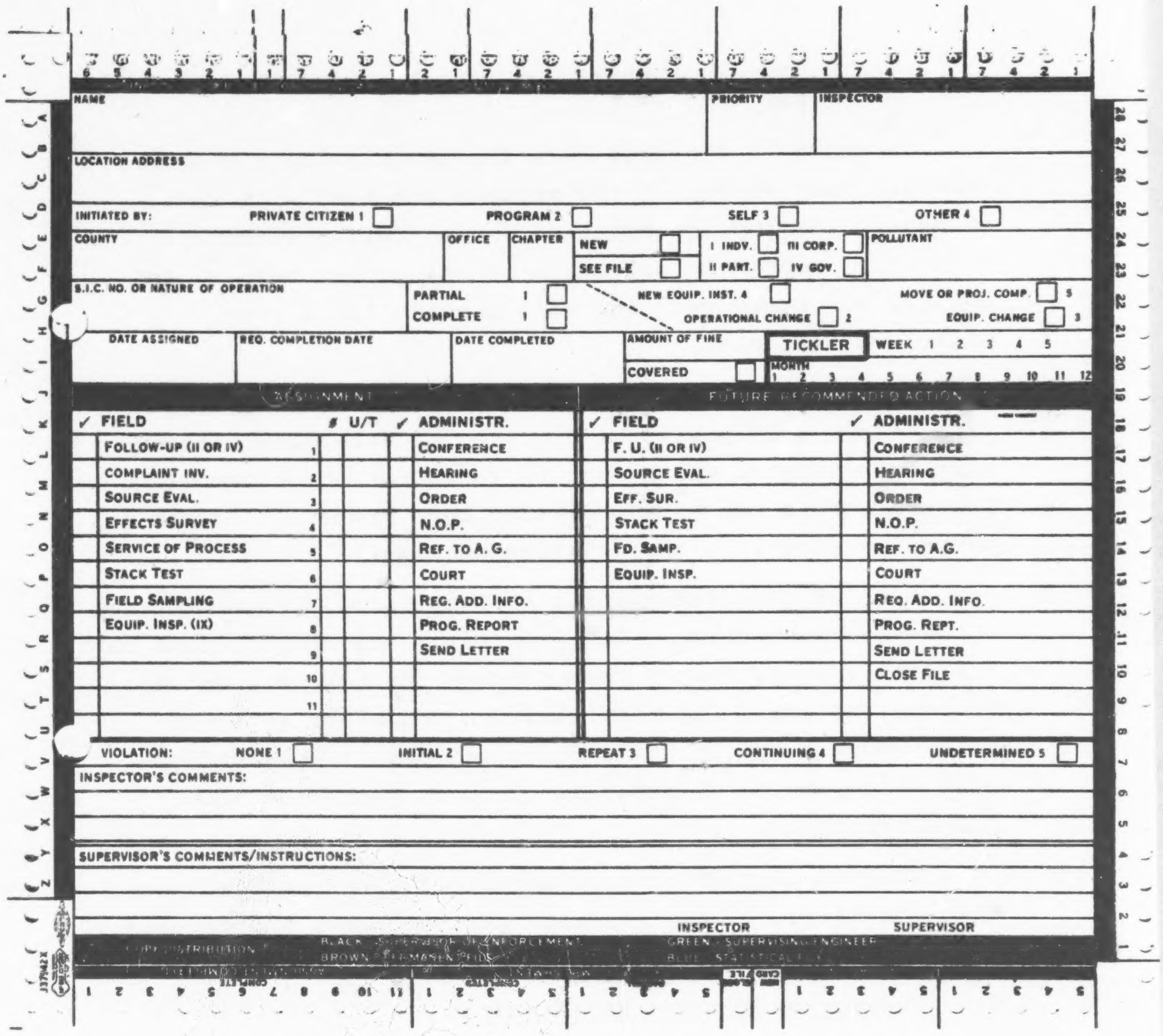
____

____

____

____

____



NAME | PRIORITY | INSPECTOR

LOCATION ADDRESS

INITIATED BY: PRIVATE CITIZEN 1 ☐ PROGRAM 2 ☐ SELF 3 ☐ OTHER 4 ☐

COUNTY | OFFICE | CHAPTER | NEW ☐ | SEE FILE ☐ | I INDV. ☐ | III CORP. ☐ | II PART. ☐ | IV GOV. ☐ | POLLUTANT

S.I.C. NO. OR NATURE OF OPERATION | PARTIAL 1 ☐ | COMPLETE 1 ☐ | NEW EQUIP. INST. 4 ☐ | OPERATIONAL CHANGE ☐ 2 | MOVE OR PROJ. COMP. ☐ 5 | EQUIP. CHANGE ☐ 3

DATE ASSIGNED | REQ. COMPLETION DATE | DATE COMPLETED | AMOUNT OF FINE | COVERED ☐

TICKLER WEEK 1 2 3 4 5

MONTH 1 2 3 4 5 6 7 8 9 10 11 12

ASSIGNMENT					FUTURE RECOMMENDED ACTION			
✓	FIELD	#	U/T	✓	ADMINISTR.	✓	FIELD	✓	ADMINISTR.
	FOLLOW-UP (II OR IV)	1			CONFERENCE		F. U. (II OR IV)		CONFERENCE
	COMPLAINT INV.	2			HEARING		SOURCE EVAL.		HEARING
	SOURCE EVAL.	3			ORDER		EFF. SUR.		ORDER
	EFFECTS SURVEY	4			N.O.P.		STACK TEST		N.O.P.
	SERVICE OF PROCESS	5			REF. TO A. G.		FD. SAMP.		REF. TO A.G.
	STACK TEST	6			COURT		EQUIP. INSP.		COURT
	FIELD SAMPLING	7			REG. ADD. INFO.				REQ. ADD. INFO.
	EQUIP. INSP. (IX)	8			PROG. REPORT				PROG. REPT.
		9			SEND LETTER				SEND LETTER
		10							CLOSE FILE
		11							

VIOLATION: NONE 1 ☐ INITIAL 2 ☐ REPEAT 3 ☐ CONTINUING 4 ☐ UNDETERMINED 5 ☐

INSPECTOR'S COMMENTS:

SUPERVISOR'S COMMENTS/INSTRUCTIONS:

INSPECTOR SUPERVISOR

COPY DISTRIBUTION: BLACK - SUPERVISOR OF ENFORCEMENT BROWN - PERMANENT FILE GREEN - SUPERVISING ENGINEER BLUE - STATISTICAL FILE

Figure 5.8 Automated source test request form - State of New Jersey.

6.0 PRELIMINARY PROCEDURES REQUIRED IN CONDUCTING A STACK TEST

In order to properly plan the stack testing program, a preliminary survey of the process and test site should be made. Information obtained during this pre-survey will help insure the selection of the proper testing and analytical procedures, and will provide for a more organized test plan.

Except in the most routine cases, an on-site inspection or pre-survey will be required to determine certain physical elements which must be known for stack sampling. These elements can be sub-divided into process information, test-site location, and emission parameters.

Much of this information will be readily obtained from an on-site inspection. Gas flow rates and compositions can frequently be estimated from process throughputs, emission factors, material balances, and fan and motor type and size. Source registration forms and permit applications will also provide information on the expected emission characteristics.

The use of construction permits for new sources can also insure the proper location of test ports and necessary scaffolding for future tests.

6.1 Pre-Survey Process Information

Process information is required in order to determine approximate emission constituents, volumes, and concentrations; and to determine the regulation which applies to the particular process being investigated. This information in turn will also have a bearing on the type of sampling equipment to be used and on the sampling schedule.

A successful stack testing program requires an intimate knowledge of the process to be tested. This can only be obtained through a careful examination of the process and thorough discussions with plant personnel. A single personal contact must be available at the plant. This person must have an understanding of the process and must also have authority to obtain required information and the cooperation of other plant personnel. A member of the plant manager's or plant engineer's staff is a desirable contact.

Pre-surveys are greatly facilitated by the use of questionnaires which list the necessary process parameters. Figures 6.1, 6.2, and 6.3 are suggested forms for combustion sources, incinerators, and industrial processes respectively which can be used for pre-surveys. These questionnaires are general guides, and in many specific cases additional information will be available. In general, the more preliminary information obtained, the better.

The cyclic operation of a process must also be determined during the pre-survey. If a process varies with time over a defined cycle, the variation in emission parameters during this cycle should be investigated. Information must be obtained to decide whether to sample over part of a cycle, over a whole cycle, or over several cycles. When the process is steady the desired level of operation must be determined. Any seasonal variation in process conditions should also be obtained.

The exact wording of the applicable regulations may also have a bearing on the desired process operating condition during the proposed tests.

Figure 6.1 Pre-Survey Form for Combustion Sources.

Name of Company ______________________________

Address ______________________________

Phone ____________ Person to Contact ____________

Date of Survey ____________ By ____________

Entry Requirements ______________________________

Location and Designation of Boiler to be Tested ____________

Type of Boiler ____________ Capacity ____________ 1000 lbs steam/hr

Type of Fuel ____________ Steam Pressure ____________ psig

Btu Value ____________ Steam Temp. ____________ °F

Sulfur Content, % by Weight ______________________________

Fuel Composition-Proximate Analysis ______________________________

Fuel Composition-Ultimate Analysis ______________________________

Type and Efficiency of Air Pollution Control Equipment ____________

____

Is Fly Ash Reinjected? ______________________________

Collection Efficiency, % ______________________________

Approximate Opacity of Stack Gases,% ______________________________

Normal Range of Steam Flucations ____________ to ____________

Can Constant Load be Maintained? ______________________________

If So, How Long? ______________________________

Figure 6.1 Continued

Conditions Under Which Boiler can be Tested:

Maximum Steam Load ______________________________

Expected Fuel Rate ______________________________

Can This be Measured? ______________________________

Excess Air Rate ______________________________

Ash Withdrawal Schedule ______________________________

Soot Blowing Schedule ______________________________

Provide complete sketchs of entire boiler and flue gas ducting. Indicate proposed location of test points, sampling port size, location of fans, location of pollution control equipment, obstructions at sampling site, necessary scaffolding, final exit stack dimensions, location of electrical power and types of sockets.

Figure 6.2 Pre-Survey Form for Incinerators.

Name of Company ______________________________

Address ______________________________

Phone ______________ Person to Contact ______________

Date of Survey ______________ By ______________

Entry Requirements ______________________________

Location and Name of Unit to be Tested ______________

____

Type of Incinerator ______________________________

Capacity ______________________________ Tons/hr

Type of Air Pollution Control Equipment ______________

Collection Efficiency, % ______________________

Normal Charging Rate ______________________

How is Charging Rate Measured?______________________

Operating Schedule ______________________

Type and Quantity of Auxiliary Fuel ______________

Excess Air Rate ______________________

Overfire and Underfire Air Rates ______________

Temperature of Flue Gases at Proposed Test Points __________

Provide complete sketchs of entire incinerator and flue gas ducting. Indicate proposed location of test points, sampling port size, location of fans, location of pollution control equipment, obstructions at sampling site, necessary scaffolding, final exit stack dimensions, location of required electrical power and type of socket.

Figure 6.3 Pre-Survey Form for Industrial Process.

Name of Company ______________________________

Address ______________________________

Phone ______________ Person to Contact ______________

Date of Survey ______________ By ______________

Entry Requirements ______________________________

Type of Process ______________________________

Location of Process ______________________________

Operating Schedule ______________________________

Process Description ______________________________

Process Feed Rates ______________________________

____

____

____

Expected Emissions

Type	Concentration	Quantity

Figure 6.3 Continued

Type and Efficiency of Air Pollution Control Equipment __________

____

Opacity of Exit Gases ______________________________

Expected Stack Gas Parameters at Test Location __________

____

Temp. °F ______________________________

Pressure, psig ______________________________

Volume, acfm ______________________________

Composition, % H_2O ______________________________

% N_2 ______________________________

% O_2 ______________________________

____

____

____

Ambient Conditions at Test Site(s) ____________________

Temperature ______________________________

Noxious Gases ______________________________

Weather Protection ______________________________

Required Safety Gear ______________________________

Provide complete sketchs of entire process and exit gas ducting. Indicate proposed location of test points, sampling port size, location of fans, location of pollution control equipment, obstructions at sampling site, necessary scaffolding, final exit stack dimensions, location of electrical power and water, etc.

6.2 Selection of Test Site

The primary criterion in selecting the test site is that the sample extracted from this site be representative of the main gas stream. Relatively little is known about the disposition of particulate within any specific moving gas stream. Therefore, every effort is made to obtain a site in which the particulate/gas mixture is as homogeneous as possible. Homogenity is best achieved in straight vertical ducts. Ideally, the gas flow should not be disturbed by any obstruction or change in direction for approximately 7 to 8 hydraulic diameters+ upstream and 2 to 4 diameters downstream from a proposed test location.[3]

In addition to flow considerations, accessibility to the site is an important consideration. Safety, as well as clearance for the probe and sampling apparatus, availability of electricity, weather exposure, presence of toxic or explosive gases, etc., must all be considered in selecting a site.

Because of these many considerations, compromises must be made in test site selection. However, one should at least strive for ideal flow conditions. In some cases, a suitable test site may not be available without major changes in the duct work. If these changes cannot be made, a meaningful sample may not be practical, and only approximate emission results will be obtained.

6.3 Preliminary Determination of Emission Parameters

In addition to general process related information, more detailed information of the gas stream parameters at the test site is desirable. This is especially true

---

+ Hydraulic diameter = $\frac{\text{Area of duct cross-section}}{\text{Duct perimeter}} \times 4$

for non-typical processes. In many cases, the exit gas composition, volume, and temperature can be approximated by material balance calculations, readings from process instrumentation, or by comparison to similar processes for which data are available. When no data can be obtained, exit gas parameters may be determined by inserting a probe into the duct at or near the test site. In this manner, an approximate velocity and temperature can be determined. Color-change detection tubes using a squeeze bulb sampler can be used to determine approximate concentrations of a wide variety of gases.

A list of the more important items required in conducting pre-surveys includes:

1. 50-1200°F dial thermometer (12" stem)
2. Velometer
3. 50-foot tape measure
4. Set of basic tools
5. Polaroid Camera
6. Detection tube samplers
7. Pre-Survey forms
8. Safety equipment

7.0 PARTICULATE SAMPLING PROCEDURES

The particulate sampling procedure used by the Office of Air Programs utilizes specialized sampling equipment and analytical procedures to obtain both a filterable and a non-filterable or condensible fraction of particulate. Special procedures are also used to insure maintenance of isokinetic sampling rates.

7.1 Measurement of Stack Gas Velocity and Related Parameters[4,5]

Prior to performing any particulate measurements, the velocity of the gas flowing through the duct at the test location must be determined. This velocity determination is a very important measurement and is composed of a number of mathematically related parameters; as shown in Equation 7.1. Not only is the total gas flow determined from this velocity measurement, but the sampling rates also depend upon this value.

$$V_s = KC_p\sqrt{\frac{T_s\Delta p}{P_sM_s}}$$

Where:
V_s = Stack gas velocity
T_s = Temperature
Δp = Velocity head
P_s = Stack gas pressure
M_s = Stack gas molecular weight
C_p = Pitot tube constant
K = Constant depending on units used

Equation 7.1

7.1.1 Location of Traverse Points

Since the velocity through any cross-sectional plane area perpendicular to the flow direction is not uniform, the area must be divided into a number of equal-sized subareas. The various parameters which affect velocity should then be determined at the centroid of each of these areas.

The average velocity is determined by taking the arithmetic average of the individual velocities; namely:

$$V_s = (\sum_{i=1}^{N} V_{si})/N$$

Where: V_s = Average velocity
V_{si} = Average velocity in any subarea
N = Number of test points

The number of subareas required to obtain a reliable average velocity is not well defined. When the test site is at least 8 hydraulic diameters downstream and 2 diameters upstream of any flow disturbances, twelve areas should be used. When these conditions cannot be met, Figure 7.1 should be used to determine the number of required points. Sampling sites less than 2 diameters downstream or one-half diameter upstream from a flow disturbance should be avoided if possible.

In circular ducts, the cross-sectional area is subdivided into concentric areas and measurements are made at four locations in each area as shown in Figure 7.2. The distances to these points which are located along the centroid of the areas are calculated by Equation 7.2.

$$Pj = 50 \left[1 - \sqrt{\frac{(2j - 1)}{2a}}\right]$$

Where: Pj = Percent of diameter from inside of duct wall to measurement point
a = Total number of areas selected = N/4
j = Number of area being calculated such as 1,2,3,4 ..... numbered from the center outward

Equation 7.2

Equation 7.2 provides only half of the distances needed. The remaining distances are obtained by taking the difference

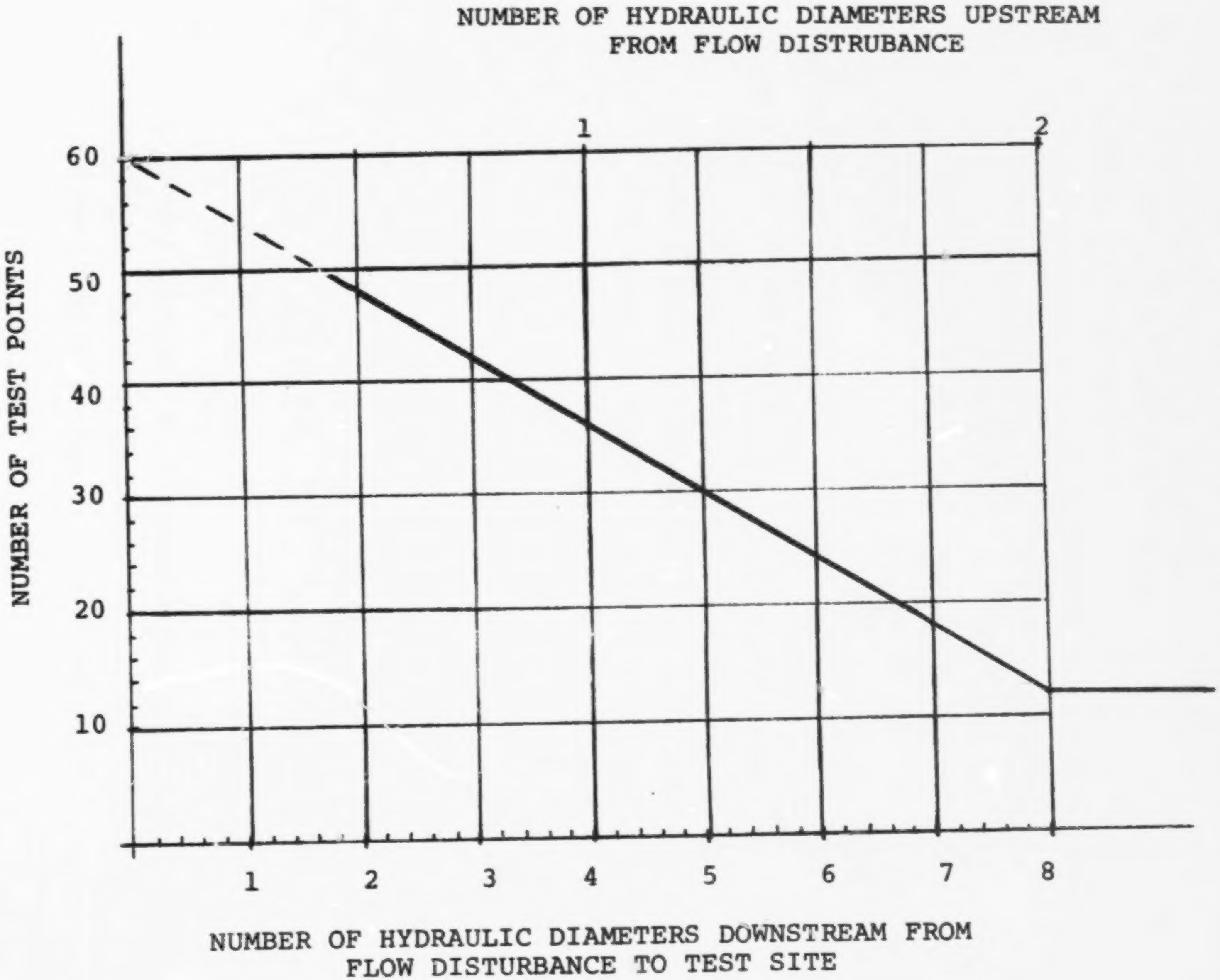
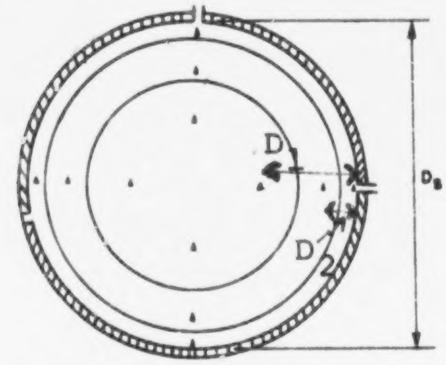


Figure 7.1 Number of test points.[6]

between each calculated percentage and 100. Table 7.1 presents the percentages determined from Equation 7.2 for up to 12 areas

For rectangular ducts, the area should be divided into approximately square subareas as shown in Figure 7.3. Measurements are made at the center of each subarea.



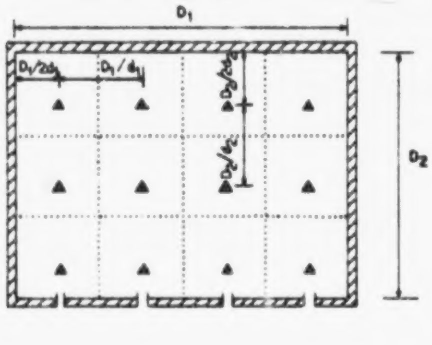
▲ Indicates sampling point

$D_1 = P_1 \times D_s$

$D_2 = P_2 \times D_s$

Where: $P_{1,2}$ is determined from Equation 7.2 or Table 7.1

Figure 7.2 Cross-section of a circular flue divided into three concentric equal areas, showing location of sampling points.



Where: d_1 = Number of areas across flue width

d_2 = Number of areas across flue perpendicular to width

and $0.5 \leq \left(\frac{D_1}{d_1} \div \frac{D_2}{d_2}\right) \leq 2$

Figure 7.3 Cross-section of rectangular flue divided into twelve equal areas with sampling points located at the center of each area.

Table 7.1 PERCENT OF CIRCULAR STACK DIAMETER FROM INSIDE WALL TO TRAVERSE POINT

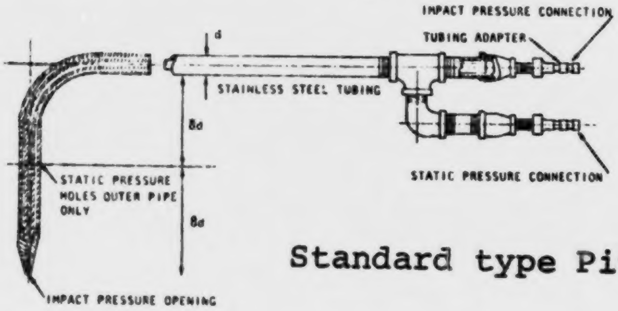
Traverse point number along diameter[a]	Number of traverse points on a single diameter[b]									
	6	8	10	12	14	16	18	20	22	24
1	4.4	3.3	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	14.7	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3	29.5	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4	70.5	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5	85.3	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6	95.6	80.6	65.8	35.5	26.9	22.0	18.8	16.5	14.6	13.2
7		89.5	77.4	64.5	36.6	28.3	23.6	20.4	18.0	16.1
8		96.7	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9			91.8	82.3	73.1	62.5	38.2	30.6	26.1	23.0
10			97.5	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11				93.3	85.4	78.0	70.4	61.2	39.3	32.3
12				97.9	90.1	83.1	76.4	69.4	60.7	39.8
13					94.3	87.5	81.2	75.0	68.5	60.2
14					98.2	91.5	85.4	79.6	73.9	67.7
15						95.1	89.1	83.5	78.2	72.8
16						98.4	92.5	87.1	82.0	77.0
17							95.6	90.3	85.4	80.6
18							98.6	93.3	88.4	83.9
19								96.1	91.3	86.8
20								98.7	94.0	89.5
21									96.5	92.1
22									98.9	94.5
23										96.8
24										98.9

a) Points numbered from outside wall toward opposite wall.

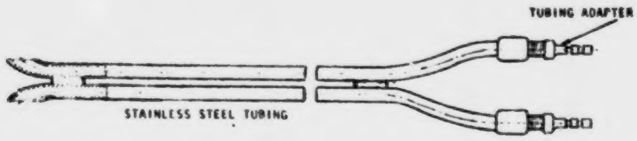
b) The total number of points along two diameters would be twice the number of points along a single diameter.

7.1.2 Velocity Head Measurements

A Pitot tube and inclined manometer are commonly used to measure velocities equivalent to at least 400 feet per minute at 60°F. A Stauscheibe or type S Pitot tube is recommended for velocity head measurements. This instrument is shown in Figure 7.4.


IMPACT PRESSURE CONNECTION
TUBING ADAPTER
d
STAINLESS STEEL TUBING
8d
STATIC PRESSURE HOLES OUTER PIPE ONLY
8d
STATIC PRESSURE CONNECTION
IMPACT PRESSURE OPENING

Standard type Pitot tube


TUBING ADAPTER
STAINLESS STEEL TUBING

Type S Pitot tube

Figure 7.4 Pitot tubes usually used to measure velocity head.

When using the type S Pitot tube, a correction factor must be applied to the velocity head readings. This factor is usually about 0.85, but can vary between 0.8 and 0.9 depending on the exact configuration of the openings. This correction factor should be checked by comparing velocity head readings taken at a point of constant air flow with a standard type Pitot tube which is also shown in Figure 7.4.

The correction factor is the ratio of the square root of the velocity head readings obtained with the Standard Pitot which has a correction factor of 1.0* divided by the square roots of the readings obtained by the Type S Pitot tube. A sample calibration calculation is shown in Table 7.2.

Table 7.2 EXAMPLE DETERMINATION OF TYPE S PITOT TUBE CORRECTION FACTOR

Standard Pitot reading		Type S Pitot reading		
H_o	$\sqrt{H_o}$	H_1	$\sqrt{H_1}$	Ratio $\frac{\sqrt{H_o}}{\sqrt{H_1}} = C_p$
0.3	0.5477	0.415	0.642	0.853
0.5	0.7071	0.700	0.837	0.844
1.0	1.000	1.44	1.200	0.833
				C_p = 0.843

The velocity head is the arithmetic difference between the total pressure and the static pressure in the duct. This difference in pressures is read on an inclined manometer by connecting the two leads on the Pitot tube to the two ends of the inclined manometer with flexible tubing, (1/4" O.D. rubber or Tygon have proven adequate). The impact or upstream end of the Pitot tube measures the total pressure and is connected to the zero end of the inclined manometer. The other leg of the Pitot tube measures static pressure and is connected to the manometer's high side.

---

* This should be calibrated by the manufacturer and could vary from 0.98 to 1.02.

Any suitable manometer may be used to read velocity head. However, the accuracy of the velocity determination depends on the accuracy of the readings obtained. As shown in Section 8, the velocity readings are the single most important factor leading to errors in source sampling work. Therefore a sensitive, easily read, instrument must be used. A manometer which can be read to within 1% of the highest expected reading is desirable.

Actual velocity head readings should not be taken until the process has been at the desired operating conditions for at least 30 minutes. During this period the distances to the required measurement points can be calculated and the Pitot tube marked. The Pitot tube can be marked with a high temperature crayon or masking tape. If the duct has a thick wall, or a pipe fitting protrudes from the wall, this dimension must be added to the distances calculated from the duct's inside wall to the test points.

Before and during the velocity traverse, the following precautions should be taken:

a) The manometer connections and tubing should be checked for leaks, kinks, or foreign matter.

b) The manometer should be carefully leveled and the liquid column set exactly on zero. This should be done after the Pitot tube has been connected to avoid disturbing the manometer. To prevent any air movement from affecting the zero setting, a cloth should be held over the end of the Pitot tube. The zero setting and level of the manometer should be checked during the test work.

c) The Pitot tube must be held at right angles to the gas flow and the impact opening of the tube must point directly into the gas stream.

d) The test ports should be kept sealed to prevent any effect on the readings by air flow.

e) In ducts with erratic velocity head readings (a common occurrence), an average value must be taken by visual observation. In taking a visual average reading, try to ignore the rapid extreme fluctuations in pressure. Glass capillary tubes inserted in the Pitot tube connecting lines will dampen out some fluctuations.

f) Only take readings at the designated subarea centers, and not at the duct edges or center.

Always use a standardized form to record velocity head readings and other pertinent test data. A suggested form is shown in Figure 7.5. Any readings which appear to be unusually high or low should be rechecked immediately.

For very low velocity measurements, a sensitive micromanometer must be used to obtain accurate velocity head readings. With this instrument readings of 0.001 inches of water can be read. Micromanometers are very sensitive to leveling and zeroing errors. If accurate velocity head readings are still not obtained, a hot-wire thermoanemometer or vane-type anemometer may be tried. These devices must be calibrated at the temperature at which they are to be used. These devices do not give accurate readings if particulate deposits on the device. When this occurs, the flow must be estimated based on material balance and/or fan data.

7.1.3 Temperature and Static Pressure Measurements

A long (36") dial stem thermometer with a range of 50 to 750°F will provide the best overall temperature measurements in ducts up to about 40 square feet in area. Though temperatures are usually fairly uniform across any cross-sectional area, a traverse with the thermometer should be made to check uniformity.

Figure 7-5 Gas Velocity and Volume Data.

Test No. ________

Location ________

VELOCITY TRAVERSE DATA

Point	Position Inches[a]	Reading, Δp "H_2O	$\sqrt{\Delta p}$	T_s °F
Total		—		
Average		—		

a) From outside of port to sampling point.

Pitot tube ________
Manometer ________
Thermometer ________

Stack Inside Dimensions ________

Stack Area = ________ sq. ft.

Barometric Pressure, P_b = ________ "Hg, Stack Gage Pressure = ________ "H_2O

Stack Abs. Pressure, P_s = $\dfrac{\text{\_\_\_\_\_\_\_\_ "}H_2O}{13.6} + P_b$ = ________ "Hg

Stack Gas Temp., T_s = ________ °F. + 460 = ________ °R

Molecular Weight of Stack Gas, M_s = ________

1. $V_s = 174\ C_p \sqrt{\Delta p T_s} \times \dfrac{29.92}{P_s} \times \dfrac{28.96}{M_s}$ ft/min

   V_s =

2. Volume = ________ ft/min x ________ sq. ft. = ________ cfm

   Standard Volume at 70°F and 29.92 "Hg:

3. $\text{cfm} \times \dfrac{530}{T_s} \times \dfrac{P_s}{29.92}$ = ________ $\times \dfrac{530}{} \times \dfrac{}{29.92}$ =

________ scfm

Data Recorder ________

Date ________

For larger ducts and for high temperatures, a thermocouple and potentiometer will be required to measure temperatures. In this case, the temperature readings should be taken at the same points and preferably at the same time that the velocity head readings are made. For temperatures in excess of about 750°F a shielded thermocouple should be used. When temperature variations occur, a continuous recording of the thermocouple readings will be useful to define the cyclic nature of the process.

All temperature data including identification of the instrument used, should be recorded on the velocity traverse data sheet (Figure 7.5).

Approximate static pressure measurements in the duct may be made by connecting one leg of a type S Pitot tube to a vertical U-tube manometer containing either water or mercury, depending on the expected range of pressure, and turning the Pitot tube sideways in the duct. The other leg of the manometer is open to the atmosphere. This static gage pressure may be either a positive (pressure) or a negative (vacuum) reading. It should be determined to the nearest one-tenth inch of water.* The absolute pressure in the duct is obtained by adding this value to the atmospheric (barometric) pressure at the test location (add the value for gases under pressure and subtract for vacuum readings). Equation 7.3 illustrates this calculation.

The atmospheric pressure is determined with an aneroid barometer, or if available, a Fortin mercury-in-glass barometer. The aneroid barometer should be checked and calibrated with a Fortin barometer. Temperature corrections must be applied to the Fortin barometer when the ambient temperature is not 32°F.*

---

* This measurement is not critical to the velocity determination, and may be ignored if it is less than about 14" of water. However, this measurement is frequently useful from a process or equipment standpoint.

$$P_s = P_b + \frac{\pm p_s}{13.6}$$

Where:
P_s = Absolute pressure in stack in inches of mercury
P_b = Atmospheric pressure at test site, inches of water, measured with a barometer
p_s = Stack gas gage pressure measured in inches of water

Equation 7.3

7.1.4 Gas Density and Moisture Determinations

In addition to the temperature and pressure of the stack gases, their density depends on composition. Many exit gas compositions are similar to air. However, for various chemical processes, this assumption may not be valid and a chemical analysis will be required. For example, gas streams from a chlorine plant may contain high concentrations of chlorine which has a molecular weight of 71. Since the molecular weight of air upon which the basic velocity equations are based is 28.96, a large difference in gas densities could lead to an error in the velocity determination.

For most combustion gases, the density is fairly close to that of air, and if no correction is applied, only a small error will result. However, the density may be checked with an Orsat analysis and the following calculation procedure:

(Percent CO_2 by volume dry basis) x 0.44 =
(Percent CO by volume dry basis) x 0.28 =

---

* Temperature corrections and other useful data are contained in ASME PTC 19.2 - 1964 - Pressure Measurement.

(Percent O_2 by volume dry basis) x 0.32 =

(Percent N_2 by volume dry basis) x 0.28 =

$\Sigma = M_d =$

$$M_s = M_d \left(\frac{100 - W}{100}\right) + 0.18W$$

Where percent CO_2, CO, O_2 are measured by Orsat apparatus, and percent $N_2 = 100 - (\%\ CO_2 + \%\ CO + \%\ O_2)$,

M_d = Average molecular weight - dry basis
W = Volume percent moisture in flue gas (see Equation 7.4)
M_s = Average molecular weight of actual flue gas

Moisture Content

Moisture content is best determined after a particulate sample has been taken since the train used to collect particulate will also collect moisture. However, a preliminary estimate of moisture content can be obtained through a knowledge of the process, a material balance, wet and dry bulb readings, by passing a measured quantity of gas through an accurately weighed desiccant, or by condensation techniques.

Passing a measured volume of stack gas through a container with an accurately weighed quantity of silica gel has been used to determine moisture content. In this case the quantity of moisture collected, divided by the sample volume will yield the percent moisture as shown in Equation 7.4. Care must be taken not to saturate the silica gel and to provide sufficient contact time for water vapor absorption.

$$W = \frac{V_{w1}}{V_m + V_{w1}} \times 100$$

V_{w1} = (Weight gain of silica gel, grams) x 0.0474*

Where: V_{w1} = ft^3 of moisture collected at 70°F and 29.92" Hg

V_m = Metered volume of dry gas at 70°F and 29.92" Hg

W = % moisture in stack gas by volume

Equation 7.4

When the full particulate sampling train is used as described in Section 7.4, moisture will be condensed in the impingers and also absorbed by the silica gel, and this quantity must be included in the total moisture calculation. Thus, if V_{w2} = (moisture condensed out in impingers, ml) x 0.0474, then:

$$W = \frac{V_{w1} + V_{w2}}{V_m + V_{w1} + V_{w2}} \times 100$$

Equation 7.5

7.1.5 Calculation of Velocity and Total Gas Flow

Calculation of stack gas velocity is not required prior to sampling if the recommended sampling method is used. The average velocity head and other stack gas parameters are however required. If needed, the velocity may be calculated according to Equations 7.6 and 7.7.

$$V_s = \left(\sum_{i=1}^{N} V_{si} \right) / N$$

$$V_{si} = K\,C_p \sqrt{\Delta p T_{si} \times \frac{28.96}{M_s} \times \frac{29.92}{P_s}}$$

Equations 7.6 and 7.7

---

* Cubic feet of equivalent vapor occupied by 1 gram of water at 70°F and 29.92" Hg.

Where: V_{si} = Stack gas velocity at point i, feet per minute
C_p = Pitot tube correction factor, (dimensionless)
Δp = Velocity head, inches of water
T_{si} = Stack gas temperature at point i, °R
M_s = Molecular weight of stack gas
P_s = Stack gas absolute pressure, inches of mercury
N = Number of sampling points
K = 174 when units listed above are used

If the molecular weight of the gas is similar to air, and the stack pressure is approximately 29.92, this equation simplifies to:

$$V_{s_i} = 174\ C_p \sqrt{\Delta p\ T_{si}}$$

The average velocity is then the arithmetic average of all the V_{s_i}. If the temperature is similar throughout the duct cross-section, the average velocity in the duct is obtained by: $V_s = 174\ C_p \sqrt{\Delta p}\ x(\text{avg.} \sqrt{T_s}\ )$. Figure 7.5 (the velocity data sheet) provides a convenient form for computing velocity and total gas volume in a duct.

7.2 Determination of Isokinetic Sampling Rates

During isokinetic sampling, the velocity of the gas entering the sampling nozzle is identical to the velocity in the duct at the sampling point. In most gas streams, isokinetic sampling is required to prevent segregation of the particulate matter and a biased sample.

Isokinetic sampling rates may be calculated if the gas velocity, temperature, pressure, nozzle area and gas metering conditions are known. These variables are related as shown in Equation 7.8.

$$Q_{m_i} = V_{s_i} A_n \frac{T_{m_i}}{T_{s_i}} \times \frac{P_s}{P_m} \times \left(\frac{100-W}{100}\right) \qquad \text{Equation 7.8}$$

Where:

Q_{m_i} = Sampling rate at meter conditions at point i, ft.^{3} per minute.

V_{s_i} = Stack gas velocity at point i, feet per minute (eq. 7.7)

A_n = Nozzle area, ft.^{2}

T_m = Average temperature of gas passing through dry gas meter, °R

T_{s_i} = Average temperature of stack gas at point i, °R

P_s = Average absolute pressure of stack gas, in. of Hg

W = % moisture in stack gas (eq. 7.4 or 7.5)

The basic orifice flow rate equation is:

$$Q_m = K_m \sqrt{\frac{\Delta H T_m}{P_m M_s}} \qquad \text{Equation 7.9}$$

Where:

Q_m = Meter flow rate, ft.^{3} per minute

K_m = Orifice calibration constant, includes orifice coefficient and unit conversions

ΔH = Pressure drop across orifice, inches of water

This relationship is obtained by calibrating the orifice and plotting the values of Q_m vsΔH on log-log graph paper.

When using the procedures described herein, an orifice with a pressure drop of about 1.84 inches of water at a flow of 0.75 cfm is recommended.

The basic isokinetic flow rate equation was given in Equation 7.8 as

$$Q_m = V_s A_n \frac{T_m}{T_s} \times \frac{P_s}{P_m} \times \frac{(100-W)}{100} \qquad \text{Equation 7.8}$$

V_s however was given by Equation 7.7

$$V_s = 174\ C_p \sqrt{\Delta P\ T_s \times \frac{28.96}{M_s} \times \frac{29.92}{P_s}} \qquad \text{Equation 7.7}$$

Substituting Equation 7.7 into 7.8 gives:

$$Q_m = 174\ C_p \sqrt{\Delta P T_s C_1} \times A_n \frac{T_m}{T_s} \times \frac{P_s}{P_m} \times \frac{(100-W)}{100}$$

Where: $C_1 = \frac{28.96}{M_s} \times \frac{29.92}{P_s}$

To determine the nozzle size, a sampling rate of 0.75 cfm* is substituted for Q_m and Equation 7.8 is rearranged and solved for A_n, the nozzle area (Eq. 7.10). An available nozzle size near the value calculated is then used to calculate the actual sampling rates at the individual traverse points.

$$A_n = \frac{Q_m}{V_s} \times \frac{T_s}{T_m} \times \frac{P_M}{P_s} \times \frac{100}{100-W} \qquad \text{Equation 7.10}$$

7.2.1 Calculation Aides

The determination of isokinetic sampling rates requires a separate calculation for every traverse point and this can be quite laborious; especially if stack gas flow conditions vary with time. Various aids have been developed to assist in this calculation. These aids, if properly used, will reduce computational errors and time, and provide a more reliable procedure for obtaining isokinetic rates.

---

* Any desired sampling rate may be used. With the equipment described here a rate of 0.75 cfm is recommended.

A straight line relationship exists between the velocity head measurements Δp, and the pressure drop ΔH, across the orifice flow rate meter used in the sampling train. This relationship along with the related variables has been plotted on nomographs as shown in Figures 7.6 and 7.7.

Variations in the assumptions used in preparing the operating nomograph (Figure 7.7) are compensated for by the auxiliary correction nomograph shown in Figure 7.6. The only variable not taken into account is the dry molecular weight of the stack gas which is assumed to be approximately equal to that of air.

The following example illustrates the procedure for using the correction nomograph and the operating nomograph with these assumed conditions:

Orifice pressure drop
ΔH @ 0.75 cfm = 2.7" H_2O from Orifice calibration, see Appendix C.

$P_s = P_m = 29.9$ in. Hg

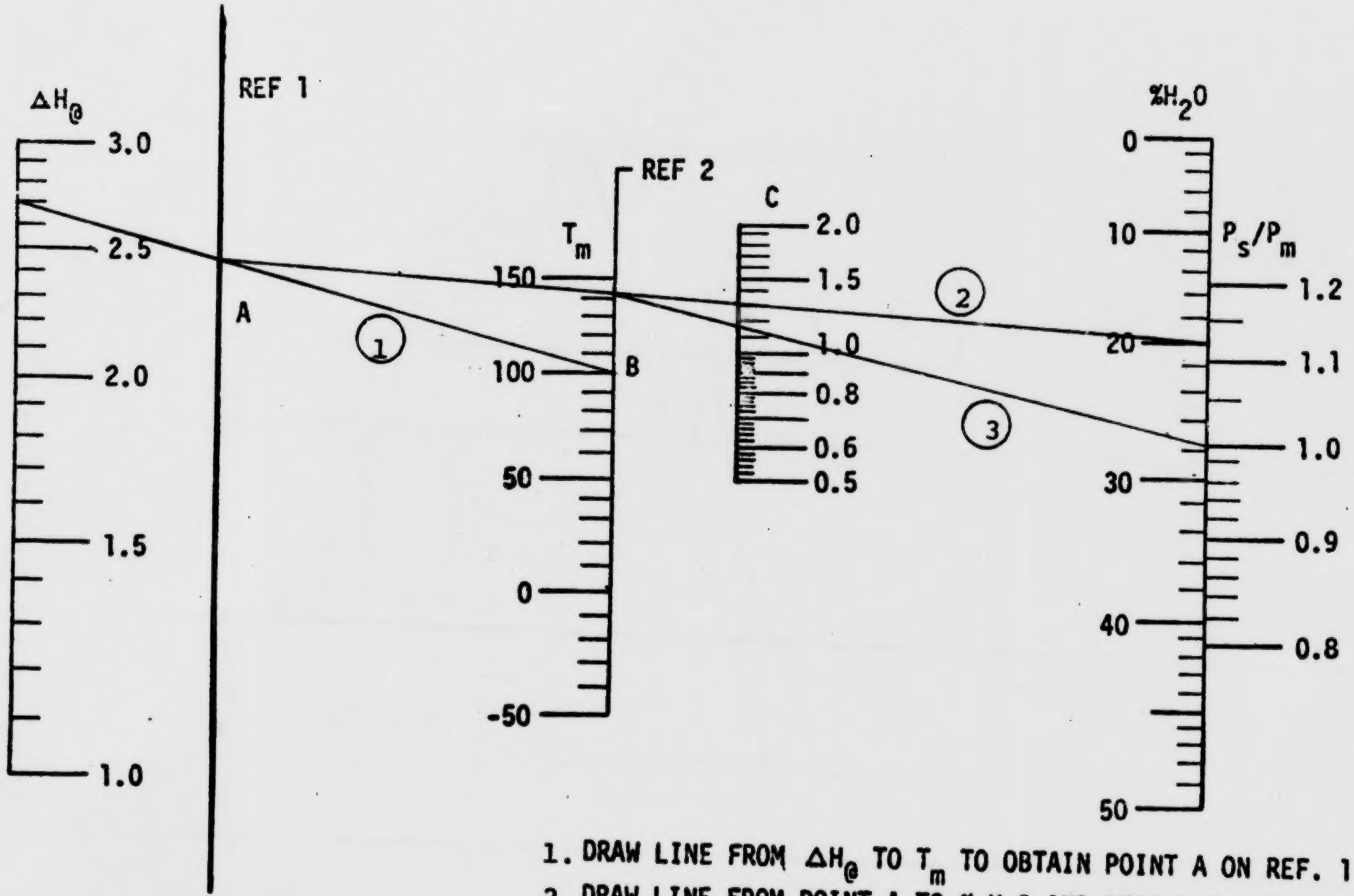
$T_s = 600°F$

$T_m = 100°F$

$W = 20\%\ H_2O$

Avg. $\Delta p = 0.36$ in. H_2O

Figure 7.6 contains instructions for obtaining the correction factor C. With the correction factor determined, the sliding portion of the operating nomograph is placed so that C is set opposite the reference mark as shown in Figure 7.7.


$\Delta H_@$
3.0
2.5
2.0
1.5
1.0
REF 1
A
①
T_m
150
100
50
0
-50
B
REF 2
C
2.0
1.5
1.0
0.8
0.6
0.5
②
③
$\%H_2O$
0
10
20
30
40
50
P_s/P_m
1.2
1.1
1.0
0.9
0.8

1. DRAW LINE FROM $\Delta H_@$ TO T_m TO OBTAIN POINT A ON REF. 1.
2. DRAW LINE FROM POINT A TO % H_2O AND READ B ON REF. 2.
3. DRAW LINE FROM POINT B TO P_s/P_m, AND OBTAIN ANSWER FOR C.

Figure 7.6 Correction Factor Nomograph.[7]

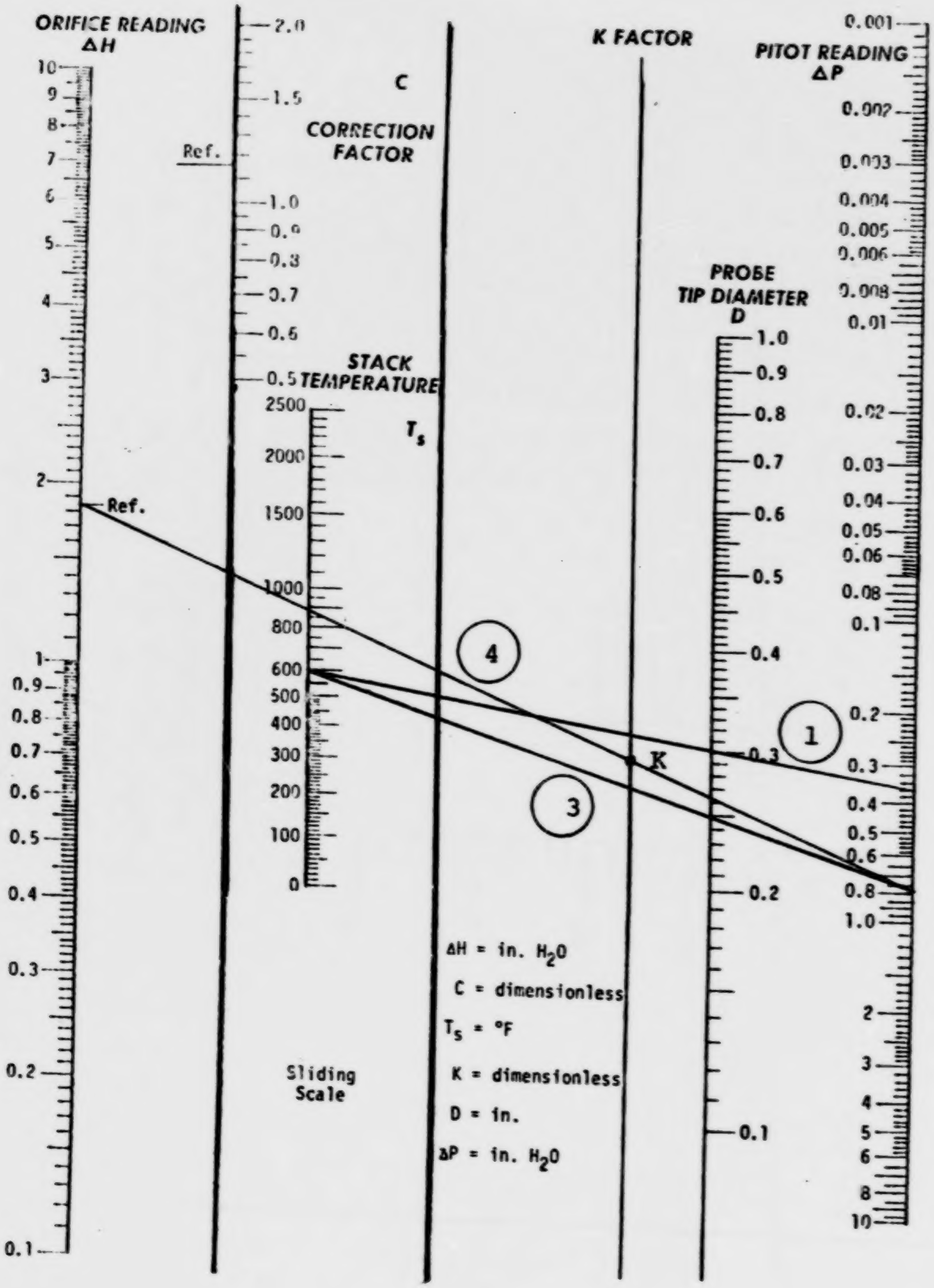

ORIFICE READING ΔH
10
9
8
7
6
5
4
3
2
Ref.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2.0
1.5
Ref.
1.0
0.9
0.8
0.7
0.6
0.5
C
CORRECTION FACTOR
STACK TEMPERATURE
T_s
2500
2000
1500
1000
800
600
500
400
300
200
100
0
Sliding Scale
K FACTOR
K
PROBE TIP DIAMETER D
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
PITOT READING ΔP
0.001
0.002
0.003
0.004
0.005
0.006
0.008
0.01
0.02
0.03
0.04
0.05
0.06
0.08
0.1
0.2
0.3
0.4
0.5
0.6
0.8
1.0
2
3
4
5
6
8
10
1
3
4
ΔH = in. H2O
C = dimensionless
Ts = °F
K = dimensionless
D = in.
ΔP = in. H2O

Figure 7.7 Operating Nomograph.[7]

The K factor must now be determined on the operating nomograph. This point will then be the pivot point which must be on the straight line connecting Δp and the desired ΔH.

Figure 7.7 illustrates this procedure.

1. Connect stack temperature to average Pitot reading p.
2. Select a probe tip diameter as close as possible to that indicated in Step 1. (In this example use 1/4").
3. Aline the actual probe tip diameter with the stack gas temperature to determine an artificial Pitot reading.
4. Aline the artificial Pitot reading with the reference mark on the ΔH axis.
5. This line crosses the K axis at the desired K pivot point.

During sampling, ΔH is determined by connecting the observed Pitot reading through K, to the ΔH scale. As long as the meter and stack gas parameters do not change very much, this K factor remains constant. If large changes are noted, a new C and K must be determined.

Unmarked copies of these two nomographs are provided in Appendix A for the reader's use.

7.3 Non-Ideal Sampling Conditions

In practice, non-ideal sampling conditions are frequently encountered due to non-uniform flow distributions and/or flow variations with time. Non-uniform flow patterns are caused by obstructions to the flow caused by fans, bends, dust collectors, duct transitions, etc. Cyclic conditions are due to the operation of the process. The degree of non-uniformity of flow, though usually evident from the configuration of the duct, can only be determined by making a traverse of the duct with the Pitot tube as discussed in Section 7.1.1.

7.3.1 Poor Flow Distribution

When sampling less than 8 hydraulic diameters downstream or two diameters upstream from a flow disturbance, the number of sampling points should be increased in accordance with the procedures in Section 7.1.1. Sampling errors will be reduced if a greater number of subareas are used to determine average emissions. When the flow pattern is tangential or spiral in nature, only approximate results will be obtained, and modification of the existing duct work should be considered.

7.3.2 Non-Isokinetic Sampling Conditions

If isokinetic sampling conditions cannot be maintained, due to stack gas flow variations or sampling train problems, a certain error in particulate measurement may occur. The degree of error will depend on the departure from isokinetic conditions, and on the particle size. Figure 7.8 presents experimental data on the expected range of error. Further work however, is still required to quantify the magnitude of these errors. In the interim, one can only try to achieve isokinetic sampling rates as closely as possible.

Particulate concentration and emission are usually determined by computing the concentration of particulate and multiplying by the volume of gas emitted (See Section 7.8). Emissions may also be computed by determining the emission rate per unit time (pounds per minute) and multiplying this ratio by the ratio of stack area divided by sampling nozzle area. By calculating the mass emission

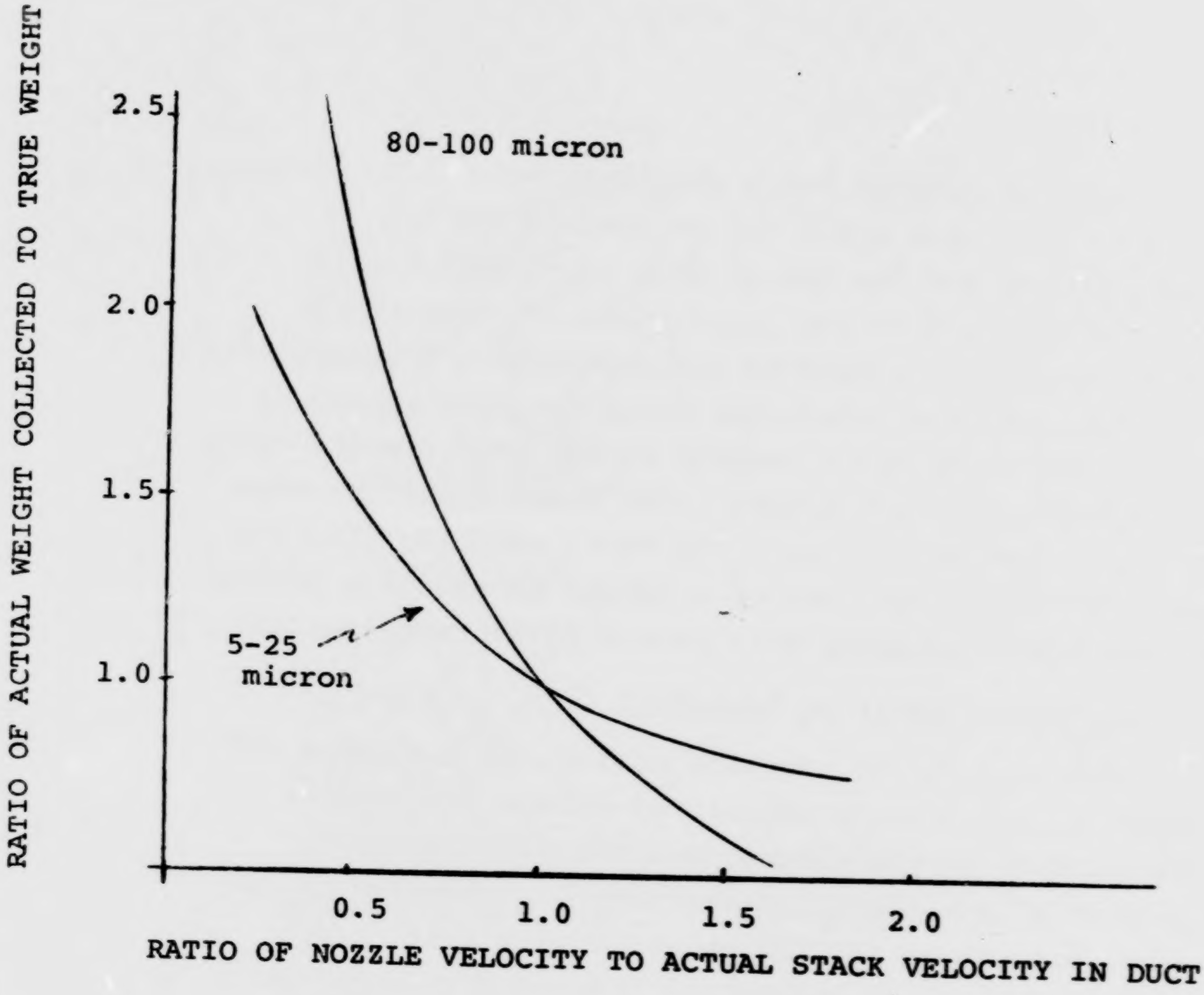


Figure 7.8 Expected Errors Incurred by Non-Isokinetic Sampling[8].
(These data should not be used to correct concentrations obtained under non-isokinetic conditions since a wide variety of particle sizes is usually present

rate by these two methods and comparing the results, the ratio of isokinetic rate actually achieved may be determined. The two methods yield identical results under exactly isokinetic sampling conditions. By selecting one calculation method or the other, or by averaging the two, more accurate emission data can be obtained.[9]

7.3.3 Cyclic Flow Conditions[10]

When gas flows and emissions vary with time, each point should be sampled for a complete cycle. For long cyclic periods, each point may be sampled for a 3 to 5 minute period and the entire duct traversed 2 to 3 times. At times, exit gas particulate concentrations and flows will be non-uniform and unsteady. This presents a difficult sampling condition since the duct should be traversed and each sample should extend over a whole cycle or specified number of cycles. For large ducts, or when long cycles are encountered, the total sampling time can become very long. The use of a number of sampling trains, operating simultaneously will reduce total sampling time.

7.4 Particulate Sampling Equipment

A wide variety of sampling trains are available for determining particulate emissions. These trains have been described in the literature, and each has its particular advantages and disadvantages depending on the sampling conditions and the object of the test.[4,5,11] In all cases however, the trains consist of a carefully sized sampling nozzle or probe tip, a probe to convey the gases, a filter or solid/gas separating device, a pump, and a gas meter. When hot gases (greater than about 150°F) are sampled, a condenser or similar cooling device is also used to protect the pump and meter.

7.4.1 Description of the Office of Air Programs' Sampling Train[7,12]

The particulate sampling train recommended and used by the Office of Air Programs is designed to measure both solid and non-filterable or condensible matter. The sampling apparatus consists of a removable probe tip, a heated probe, cyclone, heated filter, four impingers connected in series, air-tight vacuum pump, dry gas meter, and an orifice flow meter as shown in Figure 7.9. The use of the cyclone is optional and is only used for high expected grain loadings of particles greater than about 5 microns in size. This train is designed for high particulate collection efficiency and for ease in maintaining isokinetic sampling rates.

This train collects particulate matter on a filter maintained at about 250°F, and additional matter in the cooled impingers which operate in the range of 50-70°F. Thus, both a filterable and a non-filterable fraction of particulate matter are obtained. The use of a filter outside of the stack requires heating of the probe and filter to prevent condensation on the filter and subsequent high pressure drop. The use of an air-tight vacuum pump before the meter simplifies the calculations needed to determine and maintain isokinetic flow rates.

As seen from Figure 7.9, the train consists of a button-hook type nozzle or probe tip which is connected with a coupling to the probe sheath. A glass probe is inside the metal sheath.

The probe connects to a cyclone and flask when used in the train. The cyclone connects to a very coarse fritted glass filter holder, which holds a 2-1/2 inch diameter, tared glass fiber filter* When the cyclone is not used, the probe connects directly to the filter holder through an adapter tube. The cyclone, flask, and filter are contained in an electrically heated, enclosed and insulated box, which is thermostatically maintained at a minimum temperature of 250°F to prevent water condensation. Attached to the heated box is the ice-water bath contain-

---

* MSA type 1106 or equivalent.

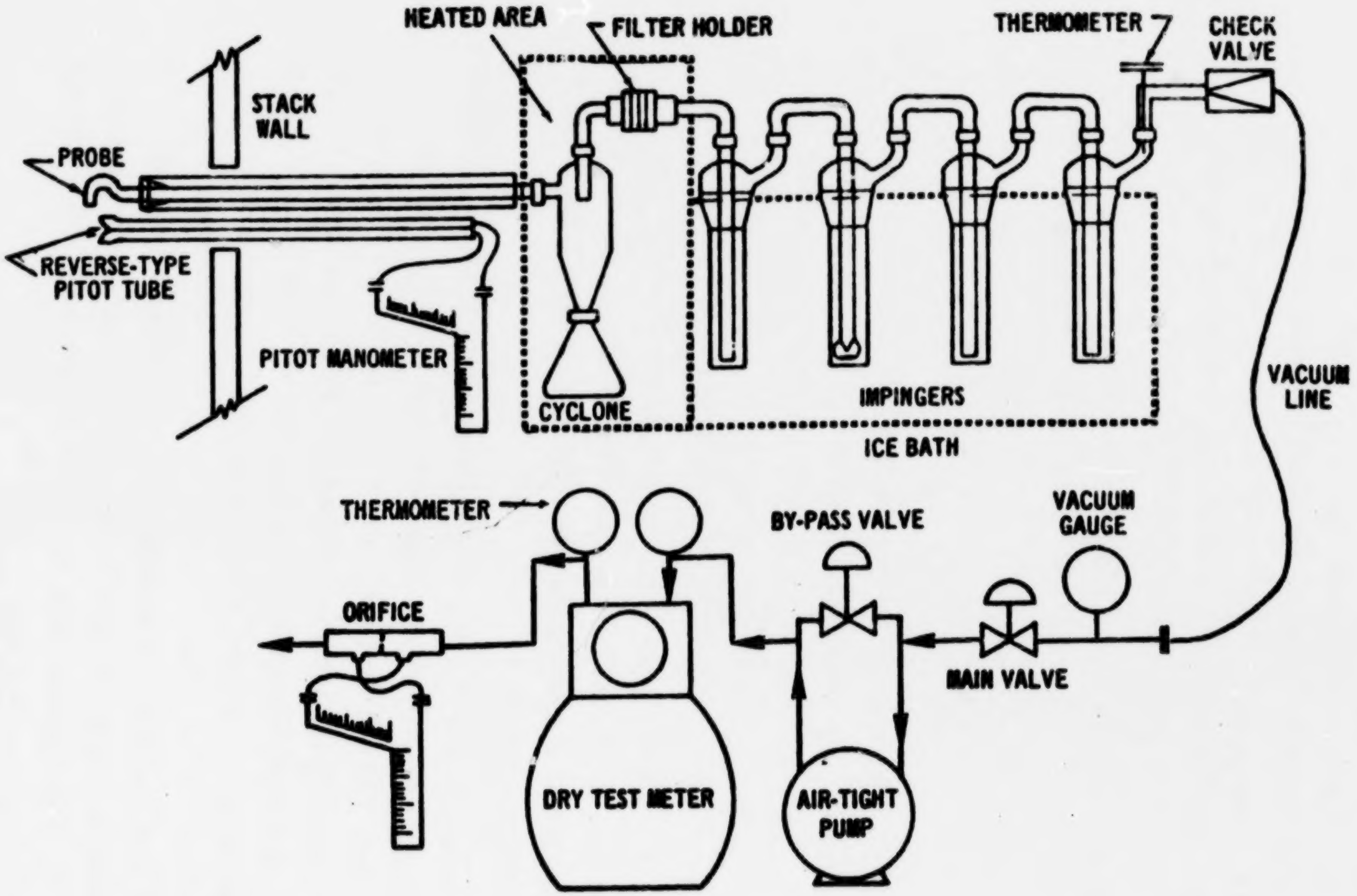

HEATED AREA
FILTER HOLDER
THERMOMETER
CHECK VALVE
STACK WALL
PROBE
REVERSE-TYPE PITOT TUBE
PITOT MANOMETER
CYCLONE
IMPINGERS
ICE BATH
VACUUM LINE
THERMOMETER
BY-PASS VALVE
VACUUM GAUGE
ORIFICE
MAIN VALVE
DRY TEST METER
AIR-TIGHT PUMP

Figure 7.9 Particulate Sampling Train Used By Office of Air Programs.7,12

ing four impingers connected in series with glass ball and socket joints. The first impinger receives the gas stream from the filter. This impinger is of the Greenburg-Smith design, but is modified by replacing the tip with a 1/2 inch ID glass tube extending to 0.5 inch from the bottom of the flask. This impinger is initially filled with distilled-deionized water* The second impinger is a standard Greenburg-Smith impinger with tip, and is also filled with distilled-dionized water. The third impinger, is a dry Greenburg-Smith impinger modified like the first. The fourth impinger is modified like the first, and contains approximately 175 grams of accurately weighed, dry silica gel.

From the fourth impinger the sampled gas flows through a check valve; flexible rubber vacuum tubing; vacuum gauge; a needle valve; and air tight vacuum pump, rated at 4 cubic feet per minute at 0 inches of mercury gauge pressure, and connected in parallel with a by-pass valve; and a dry gas meter rated at 1 cubic foot per revolution. A calibrated orifice completes the train and is used to measure instantaneous flow rates. The three thermometers used in this train are dial type, with a range of 25°F to 125°F. A fourth thermometer in the heated portion of the box has a range up to 500°F. The manometer is an inclined type graduated in hundreths of an inch of water. A similar manometer, depending on the expected range, is used to read the velocity head sensed by the Pitot tube.

Depending on the source being sampled, various modifications of this train may be made. For example for a very tarry particulate the filter may be moved to a point after the third impinger to avoid plugging.

---

* Usually 100 ml are used. Other liquids may also be used if a particular gas is to be absorbed.

7.4.2 Assembly and Testing the Train

Before assembling the various sampling components, the following procedures should be performed in the laboratory. These procedures should be completed before each test series.

It is especially important that all components which contact the sampling stream be carefully cleaned. Proper cleaning and lubrication, as described in Appendix B will also insure a leak-tight assembly.

Any other suspected malfunctions in the sampling train are also best diagnosed and fixed in the laboratory or shop. Frequent sources of mechanical problems include defective pumps (usually broken or stuck vanes), dry gas meter (erratic dial readings), timer or clock malfunctions, loose or broken electrical wires, damaged nozzle or Pitot tube openings, and cracked glass parts.

7.4.2.1 Calibration of Train Components - In addition to the Pitot tube calibration described in Section 7.1.2, the following calibrations should be made periodically.

> Meter and Orifice - The dry gas meter should be checked against a primary standard such as a large wet test meter, an accurate orifice, or a bell-prover. With the meter accuracy determined, the orifice mounted on the meter outlet can be calibrated as described in Appendix C.

Sample Box Thermostat - The thermostat in the sample box heated compartment is calibrated by comparing its set temperature with a mercury thermometer. To accomplish this, the heater and blower are turned on and the thermostat is set at 250°F. When the temperature stabilized, the reading is noted and the thermostat adjusted if required, to yield a value of 250°F. The thermostat scale is then also adjusted to indicate 250°F.

Thermometers - All thermometers used in the sampling train, and the stack gas thermometer should be periodically calibrated at a point which is near their expected operating range. For lower temperature ranges, this may be accomplished by placing the stem into hot water and comparing the readings to a mercury bulb thermometer in the same water. For higher temperatures, an oven or hot gas stream may be used for calibration checks.

7.4.2.2 Assembling Train Components - The basic assembly of the sampling train for field use is facilitated by the use of two basic units or modules and connecting hardware.

The first module is the sample box. It consists of the probe; the cyclone (if used) and filter which are placed in the heated portion of the box; and the four impingers in the cooled portion of the box. Before loading, a numbered and tared fiber glass filter is placed into the filter holder (rough face should face upstream) and the filter number is recorded on the meter data sheet. The cyclone and filter holder are clamped together at the ground glass ball and socket connectors with positive lock pinch clamps. A light coating of silicone grease is applied to the outer portion of the male ground glass joints. The inlet to the cyclone is then temporarily sealed until the train has been completely assembled and checked (a glass ball held in place with a pinch clamp has been found useful for sealing the cyclone).

The impingers are then placed into the cold section of the sampling train and the first two impingers are each filled with 100 ml of distilled, high resistance, deionized water. The third impinger is dry and the last impinger is filled with about 175 grams of weighed (± 1 gm) dry silica gel, (indicating type, 6-16 mesh). The impingers are connected with U shaped connectors and positive lock pinch clamps. The first impinger is connected to the filter outlet with a glass 'L' shaped adapter.

The second module consists of the meter box and contains the vacuum pump, dry gas meter, manometers, flow control valves, the orifice flow meter, timer, and associated connecting tubing and wiring. This module is preassembled and requires no internal field connections.

The sample box and meter box are connected by an umbilical line consisting of the main vacuum line, the two Pitot tube connection lines, four electrical wires (2 for the probe heater, and two for the sample box), and a ground wire. The vacuum line is attached to a check valve-thermometer assembly on the last impinger and connected to the meter box pump inlet with quick disconnects.

With the meter box and sample box connected, the heaters can be started and ice and water placed into the ice-water portion of the sample box. The train can then be checked as described in Section 7.4.2.4. A probe of the desired length is then selected and the appropriate nozzle is attached to the front of the probe and the probe is marked with crayon or tape to indicate the described sampling point locations. If not permanently mounted, the Pitot tube and stack gas thermometer are now also attached to the probe.

7.4.2.3 Testing the Sampling Train - To test the sampling train for proper functioning prior to a field test, the train should be completely assembled, the heaters turned on and the manometers set to zero. The vacuum pump is then turned on (with the vacuum line not connected) and a quick check is made of the orifice calibration at 0.75 cfm to determine any malfunction in the meter or orifice connections. All thermometers should be checked at this time to make sure they are reading approximately the correct values. The train is then checked for leaks by plugging the cyclone inlet, adjusting the vacuum to 10 and 15 inches of Hg respectively by closing the pump by-pass valve, and checking for flow through the dry gas meter. If a leakage rate greater than 0.02 cfm is obtained, the train should be checked for leaks. The final leakage rate should be carefully noted since the leakage volume should be subtracted from the actual sample volume during actual test work. After the leak test, release the vacuum by slowly unplugging the cyclone inlet before opening the by-pass valve and shutting off the pump. Failure to follow this procedure may cause air to flow backwards through the train and will rupture the filter. The probe assembly should now be connected to the cyclone.

7.5 Sampling Procedure

7.5.1 Location of Sampling Points - Under most conditions the location of sampling points will be the same as those used for the velocity traverse as determined in Section 7.1.1. However, points with no positive velocity readings should not be sampled. When this occurs read the velocity and proceed to the next point. Only points which lie at the centroid of the sub-areas should be sampled.

7.5.2 Length of Sampling Period - Each traverse point should be sampled for an equal time increment. A five minute sampling period per point is desirable, however 3 minutes is an acceptable minimum. A one-hour total sampling period is usually the minimum total sampling time for one test. However, this may vary considerably depending on the process. At least two tests should be made. Any test, which upon completion, is found to have contained an error in sampling or analysis, or which is not within ± 20% of the calculated isokinetic rate should be repeated. During cyclic operation, at least one complete cycle should be sampled to obtain an average particulate emission value.

7.5.3 Operation of Sampling Train - After all the equipment has been checked and found to be functioning properly, the data at the top of the Particulate Field Data Meter sheet (Figure 7.10) should be filled in. The initial dry gas meter reading should now also be carefully taken.

The cover is then removed from the nozzle tip, and the probe, along with the temperature-indicating device and Pitot tube is placed in the duct until the nozzle reaches the first sampling point. The Pitot reading and the desired ΔH found on the nomograph are recorded along with the stack temperature. Stack pressure can be ignored if it was found to be insignificant during the preliminary traverse.

To begin testing, the on-off valve is placed in the off position, the bypass valve is completely opened, and the timer is set at zero* The clock time is recorded, and the vacuum pump is turned on. The actual ΔH is adjusted to match the desired ΔH by first turning the on-off valve to on and adjusting the pump by-pass valve.

7.5.4 Recording Data during Test Period - During the test period pertinent data relating to the operation of the sampling train must be recorded in order to insure the proper operation of the train, validity of the sample, and to provide necessary data for subsequent computations.

Figure 7.10 is a sample field data form which may be used while the particulate sample is obtained. All data should be carefully entered immediately by the operator. In addition, any unusual observations in meter readings or process conditions should be noted since these might explain any results which appear to be

---

* When the stack gas is under more than about 1" of Hg gage pressure, the on-off valve should be left in the on or open position to avoid pressure build-up in the train. Sampling must then start as soon as the probe is inserted.

Figure 7.10 Particulate Field Sampling Meter Data.

Plant____________________

Run Number________________

Location__________________

Date________ Time________

Operator__________________

Sample Box Number__________

Meter Box Number___________

ΔH@______________________

Filter No.____________________

Barometric Pressure, in. Hg __________

Assumed Moisture, %________________

Assumed Meter Temp., °F_____________

Stack Gage Pressure________________ "H_2O

Probe Tip Diameter, in._____________

'C' Correction Factor_______________

Point	Time Min.	Dry Gas Meter			Velocity Head Δp "H_2O	Orifice ΔH "H_2O	Pump Vacuum "Hg	Box Temp. °F	Impinger Temp. °F	Stack Temp. °F
		Volume ft^3	Inlet Temp. °F	Outlet Temp. °F						

COMMENTS:

Leakage Rate @ "Hg = __________

anomolous. These readings should be taken at the beginning of each sample point, or if sampling at only one point, at five minute intervals.

The initial and final dry gas meter readings are most important. The Pitot readings and the stack temperature readings are also important since they will be used to compute stack gas flow upon completion of the test.

When testing has been completed, the vacuum pump should be turned off and the final set of readings taken. The heater, blower, and probe heat switches are turned off and the probe is removed from the sampling port. The nozzle tip is covered as soon as possible in order to avoid contamination or loss of sample. The probe clamp on the front of the sample box is loosened, and the probe is disconnected from the cyclone inlet. Both the end of the probe and the inlet to the cyclone are covered. After the umbilical cord has been disconnected from the sample box, the last impinger is covered, and the probe and sample box are moved to the sample cleanup area.

Various process parameters must also be recorded during the test period. The exact type of process data to be obtained will of course vary with the process. As a general guideline, all factors which have a bearing on the emissions should be recorded on approximately a 15 minute interval. These factors will include process or fuel weight rate, production rate, temperature and pressure in the reactor and/or a boiler, control equipment, fan and/or damper settings, pressure drop or other indicator of particulate collection efficiency and opacity of exit plume. Figures 7.11 through 7.13 provide sample forms for

Figure 7.11 Boiler Operating Data.

Test No. ____________________ Date ______________________

Name of Company ____

Location and Description of Boiler ______________________

____

Type of Boiler ______________ Capacity ______________ 1000 lbs steam/hr

Type of Fuel ____

Date Recorder ____

Time

Fuel Rate

Steam Rate
1000 lbs/hr

Combustion
Air Rate,
1000 lbs/hr

Steam Pressure

Steam
Temperature

I.D. Fan - RPM

I.D. Fan - Amps

Pressures H_2O

- Furnace Outlet
- Collector Inlet
- I.D. Fan Inlet

Plume Opacity

Fuel Composition (As Weighed)	Ultimate Fuel Analysis
Btu/lb	
% Moisture	
% Ash	
% S	
% Volatile Matter	
% Fixed Carbon	

Figure 7.12 Incinerator Operating Data.

Test No. ____________________ Date ______________

Name of Company ______________________________

Location and Designation of Unit ______________

____

Type of Incinerator ___________________________

Type of Control Equipment _____________________

Type of Grate _________________________________

Grate Speed ___________________________________

Type of Refuse Burned _________________________

Approx. Moisture Content ______________________

Figure 7.12 (Continued)

Data Recorder ___________

Time	Material Charged (lbs)	Primary Chamber Draft		Secondary Chamber		Plume	I.D. Fan	
		Overfire ("H_2O)	Underfire ("H_2O)	Draft ("H_2O)	Temp. (°F)	Opacity (%)	RPM	Amps
Tot.	Tot.	Avg.	Avg.	Avg.	Avg.	Avg.		

% of time Afterburners are in operation ___________

Fuel rate to afterburner ___________

Figure 7.13 Process Operating Data.

Test No. ____________________ Date ________________________

Name of Company ____

Location and Description of Process ________________________

____

Capacity and Characteristics of Process and/or Product _____

____

____

____

Raw Materials ____

Fuel Used ____

Time
____

Raw Material Feed Rate

Fuel Rate
Reactor Temp.
Reactor Pressure
Product Rate
Sidestream Rates

Recycle Stream
Rates

Exit Plume
Opacity

____

combustion, incineration, and process sources respectively. Pertinent data obtained in the preliminary plant survey (Section 6.1) should also be checked at this time.

7.5.5 Sampling Problems - Problems encountered during actual sampling are equipment malfunctions and inability to maintain isokinetic flow due to a high pressure drop through the train. Malfunctions can best be prevented through a comprehensive, routine maintenance program and a careful check of the equipment before starting to sample.

Increased pressure drop through the sampling train is usually caused by a build-up of particulate on the filter. To try to prevent this, the temperature in the filter box can be increased to about 300-350°F. Spare filters, mounted in their holder should also be prepared prior to testing in order to facilitate replacement with a new filter. If the filter is kept in a preheated box, sampling can be restarted almost immediately. The number of the new filter must be recorded immediately on the field data sheet, and the time of test interruption noted on the sheet.

7.6 Disassembly and Particulate Clean-out Procedure

Upon completion of the sampling run, the sample box is disconnected from the meter box and allowed to cool. The probe may be disconnected for ease in handling and its open ends carefully sealed. The inlet and outlet of the sampling train should also be sealed and the train transported to a clean area for disassembly. The various sampling train components are disconnected, one at a time and the collected sample is removed and placed in a numbered container. A record of the containers and the samples should be made, and the record should accompany the samples to the lab (see Figure 7.14).

First Container - Filter Holder - Remove the fiber glass filter paper from the holder and place it into a glass or inert plastic container. Use forceps in handling the filter. Any segments of the filter which adhere to the holder should be scraped off and included with the filter. Seal the container with masking tape and mark it appropriately.

Second Container - Probe, cyclone, cyclone flask, front half of filter holder and connecting tubing - The inside of these components is wiped with a rubber policeman and any loose particulate placed into the containers holding the probe contents. To remove all particulate and organic matter adhering to the inside walls, these parts should be rinsed with acetone and washed into the same container.

Third Container - Impinger liquids - Carefully pour the water from the first three impingers into a graduated flask and record the volume to within ± 2 milliliters. When determination of condensibles is desired, this water should be quantitatively poured into a container. The first three impingers and all connecting tubing are then rinsed with distilled-deionized water into the same container. If any visible particulate appears on the fritted glass filter support or the back half of the filter holder, these should also be added to this container. The container is then sealed with masking tape and labelled. If the impinger contents are not to be measured, the impinger solution may be discarded after measuring its volume.

Fourth Container - Silica Gel - The silica gel from the fourth impinger should be quantitatively transferred to a glass or inert plactic container designated as No. 4 and sealed. Use only dry brushing to remove the silica gel - no washing.

Fifth Container - Organic Matter - To insure removal of any condensed organic matter which tends to adhere to the inside walls of the glassware, the fritted glass filter support, the back of the filter holder, the first 3 impingers, and all connectors are rinsed with acetone into a container. This container is also sealed and labelled. This step may be omitted if this sample fraction is not desired.

7.7 Particulate Analysis

After the particulate fractions have been placed in their respective sealed containers, the containers should be carefully packed in a locked box, and promptly transferred to the laboratory. In the laboratory, the following analytical procedures should be performed on each of the sample containers.

First Container - The filter and any loose particulate or pieces of filter in this container should be quantitatively transferred to a tared weighing dish. This material is then dried in a desiccator until a constant weight is obtained.* For highly organic particulate matter a drying period of 2 to 3 days should be used. After drying, weigh the sample and weighing container on an analytical balance to the nearest 0.5 milligram. Record the weights on a standard laboratory form as shown in Figure 7.14.

Second Container - The acetone washings from the container are quantitatively rinsed with acetone into a clean, small tared beaker and evaporated to dryness at 70°F ± 10°F and at atmospheric pressure. The beaker and residue are then placed in a desiccator for 24 hours, and then weighed to the nearest 0.5 milligram. Record the data on the form illustrated in Figure 7.14.

Third Container - The water solution from the impingers is placed in a separatory funnel, and extracted with three - 25 cc portions of chloroform followed by three 25 cc portions of ethyl ether. The ether and chloroform extracts are combined and transferred to a clean tared beaker and evaporated at 70°F ± 10°F and one atmosphere pressure to dryness under a hood. The sample is then dried in a desiccator for 24 hours and weighed to the nearest 0.5 milligram. The water remaining after extraction is placed into a tared beaker and evaporated at 212°F. The residue is dried and weighed.

Fourth Container - The silica gel and its container is weighed to the nearest gram.

Fifth Container - The acetone washings in this container are quantitatively rinsed into a clean tared beaker and evaporated to dryness at 70°F ± 10°F and one

---

* Desiccate at 70°F ± 10°F under an atmosphere with a moisture content of less than 0.75% by volume.

(This form to accompany samples from field to lab)

WEIGHT OF PARTICULATE COLLECTED

FIELD CONTAINER NUMBER	TOTAL FINAL WEIGHT (mg.)	TARE WEIGHT (mg.)	WEIGHT GAIN (mg.)
Filter No.		______ Filter ______ Container	
Probe and Cyclone No.			
Impinger Organics No.			
Water Solubles No.			
Acetone Washings No.			

TOTAL WEIGHT OF PARTICULATE COLLECTED, W_p = x 2.2 x 10^{-6} = Pounds

x 15.4 x 10^{-3} = Grains

Plant ____________

Run No. ____________

Location ____________

Rec'd from _____ Rec'd by __

Analyzer ____________

Date Analyzed ____________

VOLUME OF MOISTURE COLLECTED

	FINAL VOLUME (ml.)	INITIAL VOLUME OR WEIGHT	VOLUMETRIC GAIN (ml.)
Impingers		-200 ml.	
Silica Gel Container No.		- gm.	

TOTAL VOLUME OF WATER COLLECTED, V_T = ml. x 0.047 = scf

Figure 7.14 Particulate Analysis Data.

atmosphere pressure under a hood. The beaker and residue are then desiccated for 24 hours and weighed to the nearest 0.5 milligram.

7.8 The Test Report

The emission test report should contain all of the pertinent data leading up to the test, a description of the process and the operating conditions under which tests were made, the results of the tests, and test procedures. The test report should enable a technically trained person to understand what was done, and what the results were. The test report may at times represent a piece of legal evidence and must therefore be carefully prepared. Summaries of field test data should be included in order to allow a knowledgeable engineer to check the results and to obtain an idea of the accuracy.

7.8.1 Format of Test Report

The exact format of the test report and the extent to which each section of the report is developed, will vary widely from agency to agency and depend mainly on the intended use of the finished report. A suggested format of the test report is presented in Table 7.3.

Table 7.3 TYPICAL FORMAT FOR TEST REPORT

1. Test Objective

This introductory section presents the reasons for performing the test series, the location of the tests, the process(es) which were tested, the location of test sites, the emissions measured, the test team and owner's personnel, the dates of the test work, and any other special comments or background information which are pertinent to the test purpose and the results.

2. Summary of Results

A summary will serve to provide a reader with a short synopsis of the tests and a tabular summary of pertinent operating and emission data.

3. Process Description

A description of the process and a schematic diagram of the flow of materials through the process are desirable in order to provide the reader with an understanding of the process. The test locations should be clearly indicated on this schematic diagram. Tables of process weight rates, temperature, gas flows, production rate, etc. which occurred during the test period should be included in this section. Capacity of the process equipment should also be included.

4. Test Results and Discussion

A detailed summary of all test results must be presented for each test run. A discussion of these results pertaining to their reliability and their relation to the process may also be presented. Variations in emissions should be explained.

5. Sampling and Analytical Procedures

The sampling techniques and analytical procedures used to obtain all emission results should be listed and referenced to a standard method. Modifications to the sampling techniques should be carefully explained when used.

6. Appendices

The appendices should contain summaries of the detailed field test data and they may contain a summary of applicable regulations.

7.8.2 Presenting the Results

Emission data should be presented in readily understood tabular form. The results should be related to the particular process or test condition in the summary tabulations. The units used to express the results will vary with the object of the stack test. In most cases, emissions on a pounds per hour or pounds per ton of process weight should be presented, in addition to a concentration value. In all cases, units identical to those used in the local regulation should be used. Specify the temperature and pressure used to convert gas volumes from stack conditions to standard conditions* Clearly indicate if a concentration value has been converted to the dry basis, and/or to a certain excess air and/or % CO_2 value.

Figure 7.15 presents a suggested data summary for particulate emissions from fuel combustion processes. Similar tabulations should be used in presenting emission data from other processes. A summary table for presenting test results which may be used in the Appendix to the report is shown in Figure 7.16.

7.8.3 Example Calculations

Reporting of emission results in a useable form always requires some calculations. These calculations are best illustrated by the following example which uses equations previously presented in this section.

7.8.3.1 Determination of Stack Gas Volume - Assume the following parameters were measured as explained in Section 7.1.

Stack dimension 60" x 72"
Stack Area, $A_s = 30 \text{ ft}^2$
Barometric Pressure, $P_b = 30.0$" Hg
Stack Gage Pressure, $P_s = 1.4$ "H_2O; $Ps = 30.0 - \frac{1.4}{13.6} = 29.9$
Stack Temperature, $T_s = 600°F = 1060°R$
Average Square Root of Velocity Head $\sqrt{\Delta p} = 0.55$" Hg.
As determined from Pitot tube traverse (Figure 7.5)
M.W., Molecular Weight of Stack Gas is similar to air (28.96)
Used Type S Pitot Tube Cp = 0.85

---

* 70°F (equivalent to 530°R) and 29.92 "Hg are usually used as standard temperature and pressure.

Figure 7.15 Format for Presenting Emissions from Fuel Combustion Units.

Test No.	Steam Rate 1000 lbs/hr	Fuel Rate	Flue Gas				Grs/ SCF	Lbs/ 1000 lbs	lbs/ 10^6BTU
			Volume SCFM[a]	Temp °F	% CO_2	% H_2O			

(a) Standard cubic feet per minute at 70°F and 29.92" Hg.

Figure 7.16 Summary of Emission Test Data[4]

Test No.
Date
Name
Address

Process Tested

1. Sampling Station
2. Material Collected
3. Operating Condition
4. Avg. Flue Gas Velocity, Ft./min.
5. Avg. Flue Gas Temp., °F
6. Area of Duct, Sq.Ft.
7. Gas Flow Rate, SCFM
8. Sampling Nozzle Diam., Inches
9. Avg. Meter Sampling Rate, CFM
10. Testing Time, Min.
11. Avg. Meter Temp., °F
12. Sample Gas Vol. - Meter Cond., CF
13. Sample Gas Vol.- Standard Cond., SCF
14. Water Vapor
    Condensate, ml.
    Volume, SCF
15. Total Sample Gas Volume, SCF
16. Weight Collected, Grams
17. Total Weight, Grams
18. Concentration, Grains/SCF
19. Concentration, Grains/SCF @ 12% CO_2
20. Concentration, percent by volume
21. Concentration, PPM by volume
22. Emission Rate, Lbs/Hr.

COLLECTOR EFFICIENCY

23. Material to Collector, Lbs/Hr.
24. Loss to Atmosphere, Lbs/Hr.
25. Efficiency, %

Test Conducted By
Analysis By
Calculations By

Gas Velocity, $V_s = 174\ Cp \sqrt{\Delta_p\ T_s \times \frac{29.92}{P_s} \times \frac{28.96}{M.W.}} =$

$$174 \cdot 0.85 \cdot 0.55 \sqrt{1060 \times \frac{29.92}{29.9}}$$

$$V_s = 80.5 \sqrt{1060} = 2620 \text{ feet/min}$$

$$Q_s = \text{Volume} = A_s \times V_s = 30 \text{ ft}^2 \times 2620 \text{ ft/min} = 78{,}500 \text{ cfm}$$

The volume at standard conditions of 70°F and 29.92 "Hg is:

$$Q_{ss} = Q_s \times \frac{530}{T_s} \times \frac{P_s}{29.92} = 78{,}500 \times \frac{530}{1060} \times \frac{29.9}{29.92} = 39{,}200 \text{ scfm}$$

This volume has the composition of the actual gas stream, but has been converted to standard conditions. Frequently it is desired to express this volume on a dry basis. This may be done by factoring out the fraction of this volume due to moisture. Thus if the gas has a moisture content, W, of 10% (as determined in Section 7.1.4) the dry volume would be $Q_{ss} \frac{(100 - W)}{100}$ or $39{,}200 \frac{(100 - 10)}{100} = 35{,}300$ scfm (dry).

The gas volume may be converted to a weight basis by multiplying by its density at a given temperature and pressure. Densities are usually determined by comparing the molecular weight of the gas with that of air, i.e., density of gas = $\frac{\text{M.W. of gas}}{28.96}$ x density of air.

In this example the molecular weight of the gas is very similar to air and therefore its density is similar; namely 0.075 pounds per ft^3 at 70°F and 29.92 "Hg.* The quantity of dry gas emitted on a weight basis is therefore:

$$35{,}200 \text{ ft}^3\text{/min} \times 0.075 \text{ pounds/ft}^3 = 2640 \text{ pounds of dry gas per minute}$$

7.8.3.2 Determination of Sample Gas Volume - The sample gas volume is equal to the gas which passed through the dry gas meter and the equivalent volume of water vapor trapped in the sampling train. If significant, the air in leakage should be subtracted from the meter volume. This quantity is then converted to a standard temperature and pressure condition as shown in Figure 7.17.

---

* Density of air at other conditions is obtained by the equation: $0.075 \times \frac{530°R}{\text{Temp.}} \times \frac{\text{Pressure}}{29.92 \text{ "Hg}}$

The particulate concentration is equal to the particulate weight divided by the sample gas volume, and the total particulate emission is equal to the product of the concentration and total stack gas flow. One must be very careful not to multiply concentrations or volume factors which are not at the same temperature, pressure, and moisture conditions. Any basis may be used, but it must be consistent throughout the calculation procedure.

7.8.3.3 Check on Isokinetic Flow Rate - A check on the rate of isokinetic flow actually maintained during the test period can be estimated on an average basis. This calculation does not insure that isokinetic flow was maintained at every instant, but it does give the average percent of isokinetic flow maintained at each sampling point. This equation which appears on the bottom of Figure 7.17. determines the ratio of the average stack gas velocity to the average velocity in the nozzle and should be between 80 and 120 at each point. Before computing individual points, a check on the test as a whole should be made to see if it falls within the specified limits.

7.8.3.4 Converting to Other Emission Standards - Frequently emissions must be expressed on a basis other than pounds per hour or grains per SCF. Other emission standards are especially popular in combustion processes where emissions are related to fuel or heat input, and to excess air rates.

Figure 7.17 Particulate Sampling Calculations

Plant No. ________________ Calculated by ____________________

Run No. ________________ Checked by ____________________

Location ________________ Date ____________________

Meter Volume ____________________ (Figure 7.10)

Leakage Volume - ____________________ (Leakage rate x sampling time)

Net Sample Volume, Q_m ____________ ft^3

Average Meter Temp. T_m ____________ °F + 460= __________ °R.

$P_m = P_b =$ ______________ "Hg

Standard Sample Volume,
$Q_{ms} = 17.7 \times Q_m \times \frac{P_b}{T_m} = 17.7 \times$ __________ $\times$ __________ $=$

Equivalent Moisture Volume, $Q_v =$ __________ SCF (Figure 7.14)

Total Sample Volume, $Q_t = Q_{ms} + Q_v =$ $=$ __________ SCF

Particulate Sample Weight, $W_p =$ _______ Grains (Figure 7.14)

Particulate Concentration, $C = \frac{\_\_\_\_\_\_}{Q_t} =$ grains/SCF

Particulate Concentration,
dry basis $C_d = C \times \frac{100}{100 - W} =$ grains/SCF-dry

Emission Rate,
lbs/hr, $E = C \times Q_{ss} \times 0.00857 =$ $\times 0.00857 =$ lbs/hr

$$\% \text{ Isokinetic, } I = \frac{V_s}{\frac{Q_t}{t \times A_n} \times \frac{T_s}{530} \times \frac{29.92}{P_b}} \times 100$$

t = sample time

A_n = area of sample nozzle, ft.^{2}

V_s = Stack gas velocity-Figure 7.5

Grains/SCF at a Specified Excess Air - Conversion to this basis requires measurement of the excess air rate. This can be determined by measuring the CO_2, O_2, and CO content of the exit gases. Excess air is then computed from the equation:

$$\% X_s = \frac{\% O_2 - 1/2\% CO}{0.264\% N_2 - (\% O_2 - 1/2\% CO)}$$

Where $\% N_2 = 100 - (\% CO_2 + \% O_2 + \% CO)$

Correction to 50% excess air for example at standard conditions is obtained by multiplying the grain loading computed at STP by the ratio: $\frac{100 + \text{measured } X_s}{150}$

For 80% excess air $C_{50\% X_s} = C \times \frac{180}{150}$

Grains/SCF at Specified Oxygen Content - Converting a grain loading to a specified O_2 content is accomplished by:

$$C \times \frac{20.9 - \text{specified } \% O_2}{20.9 - \text{measured } \% O_2}$$

Thus, if the basis is 6% O_2, and 10% O_2 was actually measured the corrected grain loading is: $C_{6\% O_2} = C \times \frac{14.9}{10.9}$

Grains/SCF at Specific Carbon Dioxide Content - Converting a grain loading to a certain CO_2 content is accomplished by:

$$C \times \frac{\text{Specified } \% CO_2}{\text{Measured } \% CO_2}$$

If the specified CO_2 content is 12%, and the measured CO_2 content in the exit gas stream was 4%, then the corrected concentration would be: $C_{12\% CO_2} = C \times \frac{12}{4}$

Pounds of Emission per 1000 pounds of Dry Flue Gas - For gas streams similar to air in composition, i.e., with a molecular weight between about 28 to 30, concentration can be approximately converted to this basis at standard conditions as follows:

$C_d \times 1.90$ at standard conditions of 70°F and 29.92 "Hg. If correction to an excess air value, or % CO_2 is also required, these corrections are applied in the same manner as previously explained. For other gas compositions or non-standard temperature or pressure conditions, the gas volume should be converted to a weight basis by multiplying by the appropriate density. The emission on a lbs/hr basis is then divided by this value.

Pounds per Million Btu - This emission expression is commonly used for combustion processes and is obtained by dividing the emission in lbs/hr by the heat input, expressed in millions of Btu entering a unit in the same hour. For bituminous coal fired units, emissions expressed on this basis can be approximated by:

$$(C_{12\%\ CO_2}) \times 1.9$$

8.0 SIGNIFICANCE OF ERRORS IN SOURCE SAMPLING

The procedure for determining pollutant emission rates by stack sampling involves the measurement of a number of parameters. Errors of measurement associated with each parameter combine to produce an error in the calculated emission rate. Measurement errors are of two types; bias and random. Bias usually occurs as a result of poor technique in which measured value tends to differ from the true value in one direction. Typically this operator error can be minimized by proper calibration and adequate training in instrument operation. Random errors result from a variety of factors which causes the measured value to be either higher or lower than the true value. They are caused by the inability to read scales very precisely, as well as the quality and sensitivity of the measurement device. The usual assumption is that random errors are normally distributed with a known (or unknown) mean and standard deviation.

The emission rate of particulates from a stack can be expressed as follows:

$$E = K_1 \, C \, Q_{ss} \qquad \text{Equation 8.1}$$

where;

E = emission rate - lb/hr
C - particulate concentration - grains/SCF
Q_{ss} = volume of gas in stack - SCFM
K_1 = constant to yield proper units

but;

$$C = \frac{W_p}{Q_t} \qquad \text{Equation 8.2}$$

where;

W_p = weight of particulate sample - grains

Q_t = total sample volume - SCF

and

$$Q_{ss} = \frac{K_2\ A_s\ Cp\ P_s}{T_s}\left[\frac{\Delta p\ T_s}{P_s\ M_s}\right]^{1/2} \qquad \text{Equation 8.3}$$

K_2 = Constant to yield

A_s = Area of Stack - ft.^{2}

Cp = Pitot tube coefficient

Δp = Velocity head of stack gas - inches H_2O

T_s = Absolute temperature of stack gas - °R

P_s = Absolute pressure of stack gas - inches Hg

M_s = Molecular weight of stack gas

Substituting 8.2 and 8.3 into 8.1 yields:

$$E = \frac{K\ W_p\ A_s\ Cp\ P_s}{Q_t\ T_s}\left[\frac{\Delta p\ T_s}{P_s\ M_s}\right]^{1/2} \qquad \text{Equation 8.4}$$

This is equivalent to:

$$E = \frac{K\ W_p\ A_s\ Cp}{Q_t}\left[\frac{\Delta p\ P_s}{T_s\ M_s}\right]^{1/2} \qquad \text{Equation 8.5}$$

The maximum relative error can be determined by use of the logarithmic differential of these equations.[13]

$$\frac{dE}{E} = \frac{d\ W_p}{W_p} + \frac{d\ A_s}{A_s} + \frac{d\ Cp}{Cp} + \frac{d\ Q_t}{Qt} + 1/2\left[\frac{d\ \Delta p}{\Delta p} + \frac{d\ P_s}{P_s} - \frac{d\ T_s}{T_s} - \frac{d\ M_s}{M_s}\right] \qquad \text{Equation 8.6}$$

The weight of particulate (W_p) is determined by the use of an analytical balance with sensitivity about ± 0.1 mg. For an industrial process the total sample weight is typically about 100 milligrams, while for some combustion processes the typical sample may be around 200 milligrams* Thus the relative error is:

$$\frac{d\ W_p}{W_p} = \pm\ \frac{0.1\ \text{mg}}{100\ \text{mg}} = 0.001 \text{ or } 0.1\% \text{ (Industrial process)}$$

$$\frac{d\ W_p}{W_p} = \pm\ \frac{0.1\ \text{mg.}}{200\ \text{mg}} = 0.0005 \text{ or } 0.05\% \text{ (Power plant)}$$

The area of the stack A_s is determined by actual measurement of length and width for a rectangular cross-section and the diameter for a circular cross-section. The areas of each type of duct are:

$$A_s = L\ W$$

or $$A_s = \frac{\pi}{4} (D)^2$$

then

$$\frac{d\ A_s}{A_s} = \frac{d\ L}{L} + \frac{d\ W}{W} \qquad \text{(rectangular)}$$

and

$$\frac{d\ A_s}{A_s} = \frac{2\ d\ D}{D} \qquad \text{(circular)}$$

A typical procedure for determining the inside measurement of a stack is to insert a rod into the stack, mark the rod, and measure with a steel rule. Such a procedure should yield a measurement correct to about 0.25 inches. Thus for a circular stack with diameter 36 inches the relative error is:

$$\frac{d\ A_s}{A_s} = \frac{2\ d\ D}{D} = \frac{2(.25)}{36} = 0.013 \text{ or } 1.3\%$$

---

* These values could of course vary widely and these values are used only as examples.

Naturally the relative error would decrease with stacks having larger inside dimensions.

The coefficient of a type S pitot tube, Cp, varies from 0.83 to 0.87. If the average is assumed to be 0.85, the maximum error is ± 0.02. The relative error is;

$$\frac{d\ Cp}{Cp} = \pm\ \frac{0.02}{0.85} = \pm \times 0.024 \text{ or } 2.4\%$$

The total sample volume Q_t is determined by;

$$Q_t = \frac{17.7\ Q_m\ P_b}{T_m} + Q_v \qquad \text{Equation 8.7}$$

where

Q_m = net sample metered volume - $ft.^3$

T_m = average absolute meter temperature - °R

P_b = barometric pressure - inches Hg

Q_v = equivalent moisture volume - SCF

$$\frac{d\ Q_t}{Q_t} = \frac{\dfrac{17.7\ P_b\ d\ Q_m}{T_m} - \dfrac{17.7\ Q_m\ P_b\ d\ T_m}{T_m^2} + \dfrac{17.7\ Q_m\ d\ P_b}{T_m} + d\ Q_v}{Q_t}$$

Equation 8.8

The volume of gas metered (Q_m) is typically between 40 and 50 cubic feet and the meter can be read to the nearest 0.01 $ft.^3$ ($d\ Q_m$). Likewise the barometric pressure (P_b) is generally near 29.9 inches Hg and can be read to the nearest 0.01 inch Hg ($d\ P_b$). The equivalent moisture volume Q_v is determined by;

$$Q_v = 0.0473\ Q_1$$

where

Q_l = moisture collected - ml

then

$$d\ Q_v = 0.0473\ d\ Q_l$$

The amount of moisture collected is quite often near 100 ml and the precision of measurement is about ± 2 ml. Thus,

$$d\ Q_v = 0.0473 \times 2$$

$$= 0.0946 \text{ or } 9.46\%$$

The absolute temperature of the meter (T_m) is determined by:

$$T_m = T + 460$$

where

T = meter temperature

$$\frac{d\ T_m}{T_m} = \frac{d\ T}{T_m}$$

This measurement of temperature is usually made with a bi-metallic thermometer with a precision of ± 2°F. The range of temperature readings is from 80-120°F. Assume an average temperature of about 100°F or 560°R:

$$\frac{d\ T_m}{T_m} = \frac{2}{560} = 0.0036 \text{ or } 0.36\%$$

Substituting these quantities in 8.8 and using the algebraic signs of each error term to produce the maximum error yields:

$$\frac{d\ Q_t}{Q_t} = 0.0006 \text{ or } 0.06\%$$

Differential pressure (Δp) is usually measured with an inclined manometer. The sensitivity is generally assumed to be about ± .01. For Δp readings near 0.05 the maximum error is:

$$\frac{d\ \Delta p}{\Delta p} = \frac{0.01}{0.05} = 0.20 \text{ or } 20\%$$

The absolute pressure of the stack gas (P_s) determined by Equation 7.3; namely:

$$P_s = \frac{\pm\ p_s}{13.6} + P_b$$

where

p_s = stack gage pressure - inches H_2O

$$\frac{d\ P_s}{P_s} = \frac{\frac{d\ p_s}{13.6} + d\ P_b}{P_s}$$

Stack gas pressure (p_s) is measured with a manometer which can be read to the nearest 0.1 inches of water (d P). Typically the stack gas pressure is around ± 2 inches of water then;

$$\frac{d\ P_s}{P_s} = 0.0004 \text{ or } 0.04\%$$

Stack gas temperature (T_s) measurements are usually made by mercury-glass thermometers, thermocouples, liquid-filled bulb-thermometers, or bi-metallic thermometers. Typical properly calibrated thermometers are accurate to within ± 5°F from 32°F to 500°F, ± 10°F from 500 to 1000°F, and ± 20°F from 1000°F to 2000°F. The maximum relative error would occur at about 1000°F.

$$\frac{d\ T_s}{T_s} = \pm \frac{20}{1000 + 460} = 0.014 \text{ or } 1.4\%$$

The equation for dry molecular weight in terms of Orsat readings for a typical combustion process is:

$$M_d = \frac{1}{100}\left[M_{CO_2} \quad (R_{CO_2} - R_0) + M_{0_2} \quad (R_{0_2} - R_{CO_2}) + \right.$$
$$\left. M_{CO} \quad (R_{CO} - R_{0_2}) + M_{N_2} \quad (100-R_{CO}) \right]$$

Equation 8.9

where:

M_{CO_2} = 44-molecular weight CO_2

M_{0_2} = 32-molecular weight 0_2

M_{CO} = 28-molecular weight CO

M_{N_2} = 28-molecular weight N_2

R_0 = Initial reading of ORSAT

$R_{CO_2}, R_{0_2}, R_{CO}$ are ORSAT readings for each gas

Substituting the molecular weights into equation 8.9 and differentiating yields:

$$\frac{d\,M_d}{M_d} = \frac{-0.44\ d\ R_0 + 0.12\ d\ R_{CO_2} + 0.04\ d\ R_{0_2}}{M_d}$$

Equation 8.10

The error in reading the gas burette is generally ± 0.2 percent by volume and a typical dry molecular weight is about 29. Thus the maximum error is:

$$\frac{d\,M_d}{M_d} = 0.0042 \text{ or } \pm 0.42\%$$

The maximum relative error in the emission rate (equation 8.6) can be found by summation of all of the above errors.*

$$\frac{dE}{E} = (0.1) + (1.3) + (2.4) + (0.06) + \frac{1}{2}\Big[(20) + (0.04) + (1.4) + (0.42)\Big] = 14.8 \text{ percent}$$

Again, it should be emphasized that 14.2% is the maximum relative error if all of the individual errors are additive and not random.

A more realistic way of expressing error is to consider the error in terms of standard deviations. In this case, the error is expressed as 3 deviation (3σ) units about the mean.[14] The probable error can be calculated from;

$$3\sigma = \left[\Sigma_{l=1}^{h} A_l^2 \, (3\sigma_l)^2\right]^{1/2} \qquad \text{Equation 8.11}$$

thus

$$3\sigma_E = \left\{(0.1)^2 + (1.3)^2 + (2.4)^2 + (0.06)^2 + 1/4\left[(20)^2 + (0.04)^2 + (1.4)^2 + (0.42)^2\right]\right\}^{1/2}$$

$$= 0.104 \text{ or } 10.4 \text{ percent}$$

On the basis of this error analysis, the determination of emission rates by isokinetic stack sampling can be expected to be within 10.4 percent of the true mean 99.6 percent of the time. It is apparent that most of the sources of error contribute only in a very small way to the total error in the calculated emission rate. The most significant error results from the measurement of differential pressure (Δp) with the pitot tube.

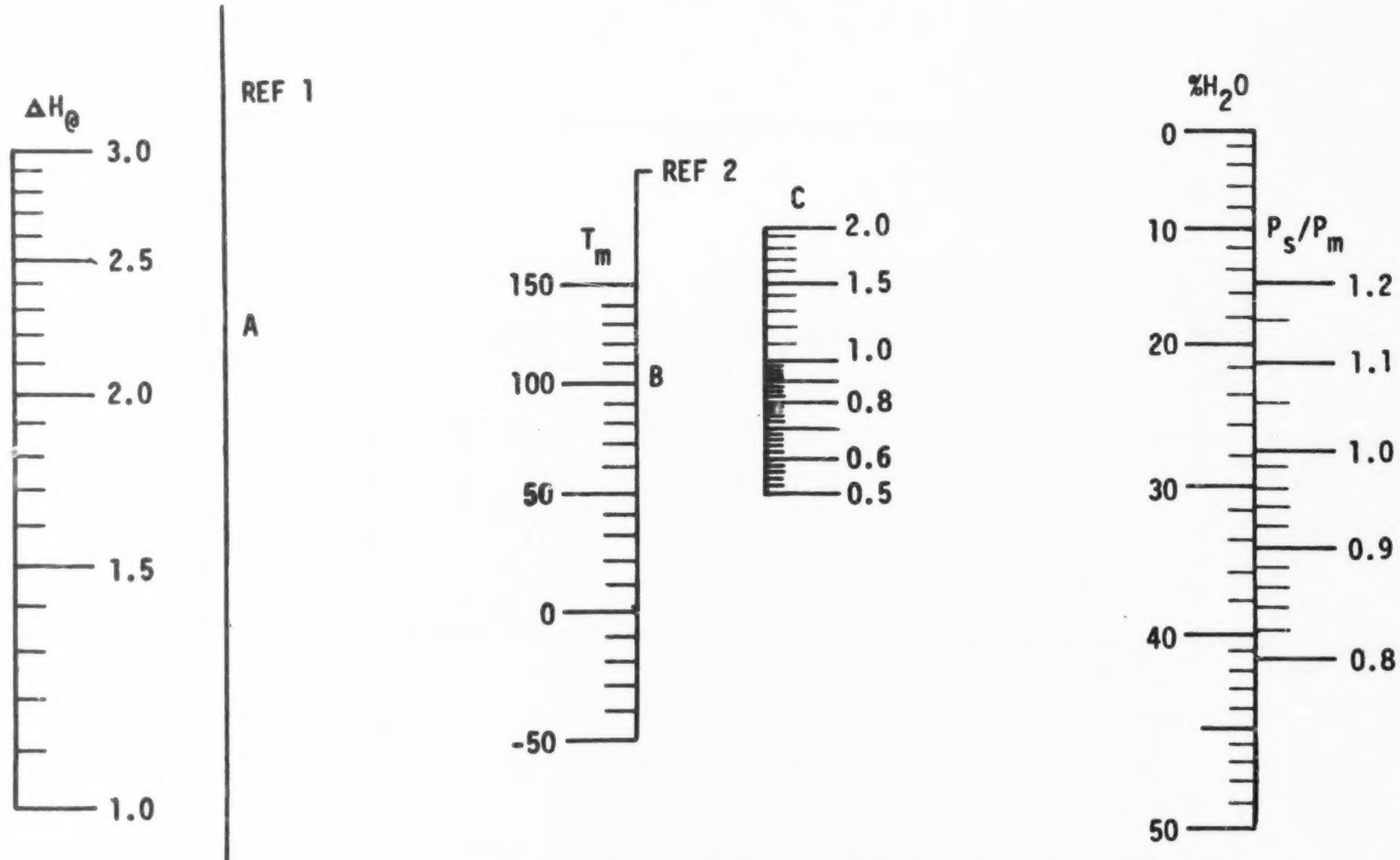
---

* The error associated with the dry molecular weight, M_d is used as the error for the actual stack gas, M_s.

APPENDIX A

NOMOGRAPHS FOR USE WITH SAMPLING TRAIN

BLANK PAGE


$\Delta H_@$
3.0
2.5
2.0
1.5
1.0
REF 1
A
REF 2
T_m
150
100
50
0
-50
B
C
2.0
1.5
1.0
0.8
0.6
0.5
$\%H_2O$
0
10
20
30
40
50
P_s/P_m
1.2
1.1
1.0
0.9
0.8

DRAW LINE FROM $\Delta H_@$ TO T_m TO OBTAIN POINT A ON REF. 1.
DRAW LINE FROM POINT A TO % H_2O AND READ B ON REF. 2.
DRAW LINE FROM POINT B TO P_s/P_m, AND OBTAIN ANSWER FOR C.

Figure A1. Correction Nomograph For Use With Figure A2.

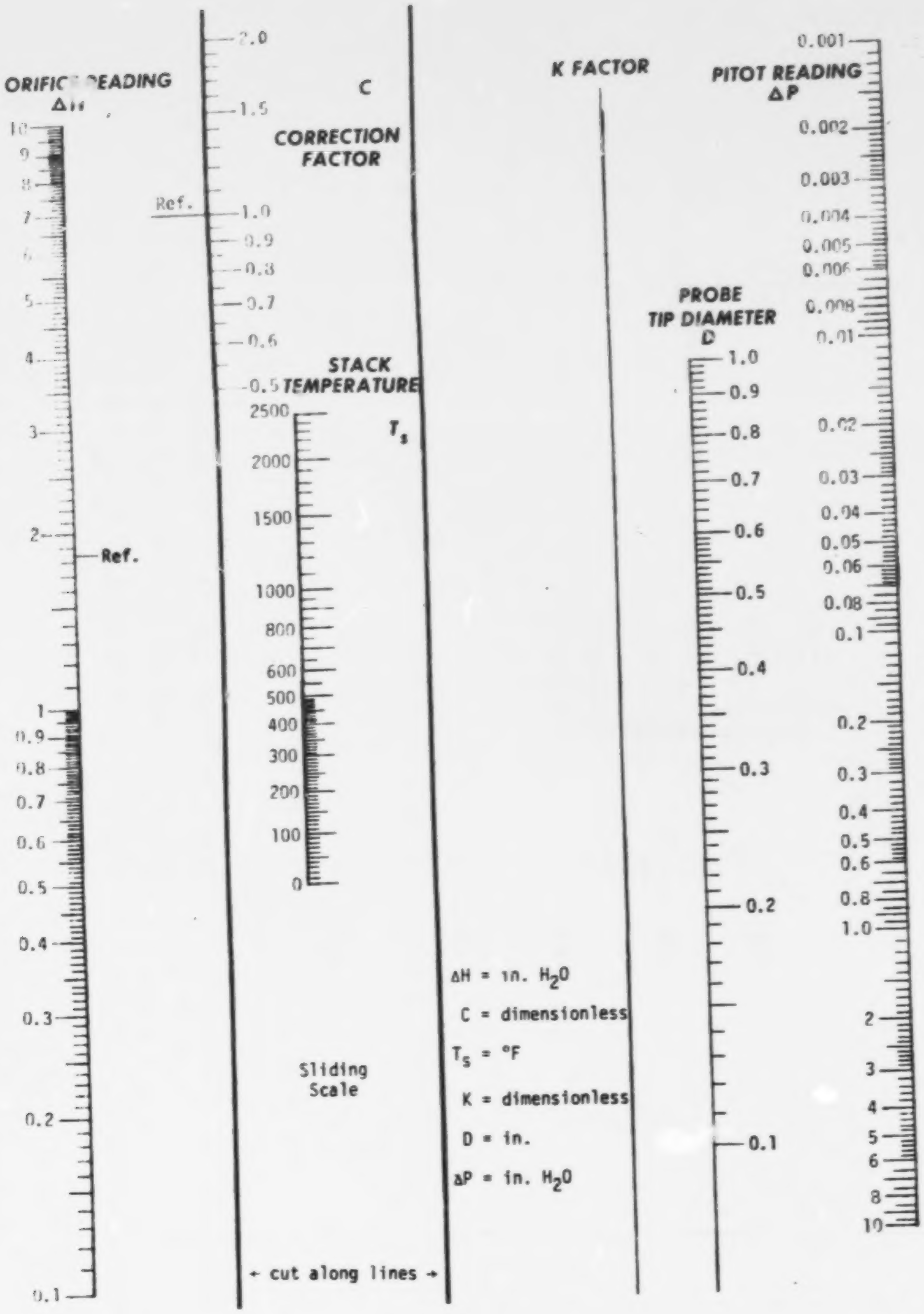

ORIFICE READING ΔH
C CORRECTION FACTOR
STACK TEMPERATURE T_s
K FACTOR
PITOT READING ΔP
PROBE TIP DIAMETER D
Ref.
Ref.
Sliding Scale
← cut along lines →
ΔH = in. H_2O
C = dimensionless
T_s = °F
K = dimensionless
D = in.
ΔP = in. H_2O

Figure A2. Operating Nomograph.

APPENDIX B

Cleaning of Train Components[16]

Small Metal Parts - Small stainless steel parts including quick connects, nozzles, check valves, unions, and socket joints should be cleaned with water and a detergent by hand, or with a sonic cleaning device and the recommended cleaner. The parts are then rinsed with distilled deionized water and then with acetone to remove organics and promote drying. Quick connects and check valves should be lubricated very lightly with silicone grease and the openings covered.

Probe Sheath and Pitot Tube - The probe is first stripped of the stainless steel union and quick connects. These parts are cleaned together with the small metal parts. The rubber o-ring is cleaned using first water and then acetone. The Pitot tube and probe sheath are scrubbed with acetone and water and the Pitot tube is blown out with compressed air. After cleaning, the unions and quick connects are reassembled. The glass probe is inserted in the metal sheath and the openings covered until ready for use.

Glass Probe - Grease is wiped from the ground glass ball joint and the probe brushed and rinsed first with distilled, deionized water and then with acetone. A visual inspection is made to determine if the probe is thoroughly clean inside. The dried glass probe is placed in the cleaned stainless steel probe sheath and the ends covered to avoid contamination.

Glass Parts - All ground glass joints are wiped to remove any remaining grease. All pieces are then soaked in a cleaning solution of dichromate and acid for twenty-four hours. The parts are then washed in soap and water, rinsed with distilled, deionized water then acetone. A very thin coat of acetone insoluble silicone stopcock grease is then applied to all of the inside (female) ground glass joints. The impingers are then reassembled. The glass, field sample containers and related glass clean-up equipment should be cleaned using this procedure. All openings on the glass parts should be covered to avoid contamination.

Filter Frit - The extra course glass frit from the filter holder is cleaned by placing it in boiling hydrochloric acid (under a hood) for two hours and rinsing in distilled, deionized water followed by an acetone rinse. If the frit does not appear clean, it should be boiled for two hours in H_2SO_4 containing a few drops of sodium or potassium nitrite and rinsed in distilled, deionized water and acetone, and left to dry.

Miscellaneous - Manometers should be cleaned using either soap, naphtha, or gasoline. No other solution should be used to clean the manometer unless recommended by the manufacturer. The manometers are then refilled with the appropriate liquids.

APPENDIX C

ORIFICE CALIBRATION PROCEDURE[15]

The meter box containing the vacuum pump and dry gas meter is connected to a large capacity wet test meter (1 cubic foot per revolution) by connecting the meter box inlet to the outlet of the wet test meter. The orifice manometer is carefully zeroed. The vacuum pump is then turned on, the orifice ΔH is set at 0.5" of water and the system is run for 15 minutes to equilibrate the temperatures. The following readings are taken during the meter/orifice calibration. (1) Cubic feet of air registered by the dry gas meter (CF_d), (2) temperature of the wet test meter in °F (T_w), (3) inlet temperature of the dry gas meter in °F (IT_d), (4) outlet temperature of the dry gas meter in °F (OT_d), (5) time in minutes (t) required for 5 cubic feet of air to flow through the train, and (6) barometric pressure in inches of mercury (P_b). The same procedure is used with the manometer orifice setting at a ΔH of 1 inch of water, and the same data are recorded. With the manometer orifice set at ΔH readings of 2, 4, 6, and 8 inches of water, respectively, 10 cubic feet of air are allowed to flow through the wet test meter at each of these settings, and the same data are recorded. From those data, Y and $\Delta H_@$ are determined for each calibration point. Y is the ratio of accuracy of the wet test to the dry gas meter. $\Delta H_@$ (inches of H_2O) is the orifice differential that gives 0.75 cfm of air at standard conditions of 70°F and 29.92 inches of mercury. Figure C-1 illustrates a convenient form for recording these data and also gives the formulas used to calculate Y and $\Delta H_@$.

If the calculated value for Y is not between 0.99 and 1.01, the dry gas meter will require adjustment as per the manufacturer's instructions. If the flow through the orifice at a setting of 1.84 ± 0.25 inches of H_2O is not 0.75 cfm, the orifice diameter should be increased or decreased as the case may be.

Once determined, $\Delta H_@$ is constant for a given meter and orifice assembly, and should be recorded on the meter box.

Figure C-1 Orifice Calibration Form.

Date______Box No. ______________Meter No. ______ P_b__________

ΔH, In. H_2O	CF_w	CF_d	T_w, °F	IT_d, °F	OT_d, °F	T_d, °F	Time, t (Min.)
0.5	5						
1.0	5						
2.0	10						
4.0	10						
6.0	10						
8.0	10						

Calculation Y and $\Delta H_@$ at manometer orifice setting of 2.0

$$Y = \frac{CF_w \cdot P_b \cdot (T_d + 460)}{CF_d \cdot (Pb + \frac{\Delta H}{13.6})(T_w + 460)} = \underline{\qquad\qquad\qquad\qquad}$$

$$\Delta H_@ = \frac{0.0317\ \Delta H}{P_b\ (OT_d + 460)} = \frac{(T_w + 460)\ t}{CF_w} = \underline{\qquad\qquad\qquad}$$

Y - Ratio of accuracy of wet test meter to dry gas meter.

$\Delta H_@$ = Orifice pressure differential that gives 0.75 cfm of air at 70°F and 29.92 inches of mercury, in. H_2O.

P_b = Barometric pressure, in. Hg.

ΔH = Manometer orifice setting, in. H_2O.

CF_w = Cubic feet of air measured by the wet test meter, cubic feet.

CF_d = Cubic feet of air measured by the dry gas meter, cubic feet.

T_w = Temperature at the wet test meter, °F.

IT_d = Inlet temperature at the dry gas meter, °F.

OT_d = Outlet temperature at the dry gas meter, °F.

T_d = Average of the inlet (IT_d) and outlet (OT_d) temperatures at the dry gas meter, °F.

t = Time of test, minutes.

Tolerances

Y = 0.99 - 1.00 - 1.01

$\Delta H_@$ = 1.6 - 1.84 - 2.1

LIST OF SYMBOLS

A_n	Area of Sampling Nozzle, ft.^{2}
A_s	Inside Area of Stack, ft.^{2}
C	Particulate Concentrations, Grains/SCF
Cp	Pitot Tube Correction Factor, No Units
E	Emission Rate, lbs/hr.
M_s	Stack Gas Molecular Weight
M_d	Stack Gas Molecular Weight Dry Basis
N	Number of Sampling Points
P_b	Barometric Pressure, Inches of Hg
P_s	Stack Gage Pressure, Inches of Water
P_s	Stack Absolute Pressure, Inches of Hg
P_m	Average Pressure at Dry Gas Meter, Inches of Mercury (as used in this text $P_m = P_b$)
Q_s	Stack Gas Volume, cfm
Q_{ss}	Stack Gas Volume SCFM
Q_m	Meter Volume, CF or rate, CFM
Q_v	Volume of Condensed Moisture, SCF
Q_{ms}	Meter Volume, SCF
Q_t	Total Sample Volume, SCF
T_m	Meter Temperature, °F.
T_s	Stack Gas Temperature, °F.
V_s	Stack Gas Velocity, ft/min.
W	Moisture Content of Stack Gas, %
Δp	Velocity Head, Inches of Water
ΔH	Pressure Drop Across Orifice, Inches of Water
W_ρ	Particulate Weight, Grains or Grams

REFERENCES

1. Walsh, G. W. and D. Von Lehmden. Resources for Air Quality Control Regions. (Presented at EPA Workshop on Regional Implementation Plans. Raleigh, North Carolina, November 1969).

2. Ermenc, E. D. Air Pollution Control Governmental Careers. Chemical Engineering. 78(1): 122-125, January 11, 1971.

3. Standard Test Code for Centrifugal and Axial Fans. Published by National Association of Fan Manufacturers. Bulletin No. 10. 1938.

4. Devorkin, H., etal. Source Testing Manual, Los Angeles, Los Angeles County Air Pollution Control District, November, 1963. 179 p.

5. Sampling Stacks for Particulate Matter. ASTM Method D 2928-71. Philadelphia, Pa. January 1971.

6. Sample and Velocity Traverses for Stationary Sources -- Method 6. (Tentative). Office of Air Programs, EPA Raleigh, North Carolina. May 1971. 4 p.

7. Smith, W. S., etal. Stack Gas Sampling Improved and Simplified with New Equipment. Paper No. 67-119. (Presented at the Air Pollution Control Association Annual Meeting, Cleveland, Ohio, June 11-16, 1967).

8. Hemeon, W.C. Magnitude of Errors in Stack Sampling. Air Repair. 4: 159-164, November 1954.

9. Smith, W. S., R. T. Shigehara, W. F. Todd. EPA A Method to Interpret Sampling Data. Paper No. 70-34. (Presented at the Air Pollution Control Association Annual Meeting, St. Louis, June 14-18, 1970).

10. Achinger, W. C. and R. T. Shigehara. A Guide for Selecting Sampling Methods for Different Source Conditions. J. Air Pollution Control Association. 18:605-609, September 1968.

11. Bulletin WP-50. Western Precipitation Company, Los Angeles, California. 6th Edition. 27p.

12. Martin, R. M. Construction Details of Isokinetic Sampling Equipment As Developed and Used by Office of Air Programs - In press. Office of Air Programs, EPA. Raleigh, North Carolina.

13. Shigehara, R. T., W. F. Todd, and W. S. Smith. Significance of Errors in Stack Sampling Measurements. Paper No. 70-35. (Presented at the Air Pollution Control Association Annual Meeting, St. Louis, June 14-18, 1970).

14. Wine, R. L. Statistics for Scientists and Engineers. Englewood Cliffs, New Jersey, Prentice-Hall, Inc. 1964.

15. Rom, J. Source Sampling Using APCO Designed Equipment. In Press. Office of Air Programs, EPA. Raleigh, North Carolina. 1971.